
Optimization of Financial Services Transaction Management Based on Blockchain Empowerment and Hierarchical Clustering

Abstract:

This study aims to enhance the efficiency of service transaction management in the contemporary financial industry. The approach involves three main steps. First, a Hyperledger Fabric blockchain network is established, and smart contracts are deployed to ensure the tamper-proof nature and transparency of transaction data. Second, a hierarchical clustering algorithm (HCA) is applied to thoroughly analyze the transaction data, uncovering potential patterns and structures. Finally, a performance evaluation experiment of the model is conducted, wherein a variety of financial transaction data are collected, comprehensively processed, and analyzed.

The research findings demonstrate that integrating blockchain technology with the hierarchical clustering method significantly boosts transaction management efficiency and data security. Specifically, this integrated approach improves transaction processing speed by more than 30% compared to traditional methods and shows marked efficiency improvements across various transaction volumes. Blockchain technology ensures data integrity, preventing tampering, while the detection rate of abnormal transactions increases to 99%, greatly enhancing system security.

These results underscore the practical application value of the fusion method in financial service transaction management. This study not only promotes further development and innovation in financial service transaction management but also provides more efficient and secure solutions for the fintech sector.

Keywords: Blockchain, Hierarchical Clustering, Financial Services, Transaction Management

1 Introduction

At present, traditional transaction management in financial services faces multiple challenges, such as difficulties in ensuring the authenticity and consistency of transaction data, low efficiency in transaction processing, and data security issues (Yin & Wang, 2023; Pazarbasioglu, 2020). The traditional centralized system is prone to single points of failure and system bottlenecks when handling large volumes of transaction data, leading to delays and increased costs (Karagiannis, 2019). The advent of blockchain technology has introduced new possibilities for financial service transaction management (Lorenzo & Arroyo, 2022; Risius & Spohrer, 2017). As a distributed ledger technology, blockchain excels in addressing trust issues in traditional financial systems and enhancing data security through decentralization, immutability, and transparency (Esfahani, 2022; Song et al., 2022; Chang et al., 2020; Chong, 2021).

The application of blockchain technology in the financial sector encompasses cross-border payments, smart contracts, and digital identity verification, among others (Zanella et al., 2021). By recording transaction information on the blockchain, data tampering and fraud can be effectively prevented, thereby enhancing the transparency and credibility of transactions (Muneeb et al., 2021; Tapscott & Tapscott, 2016).

However, blockchain technology alone cannot address all transaction management challenges, particularly in data processing and analysis, and requires optimization through the integration of other technical approaches (Wu & Duan, 2019; Javaid et al.,

2022). Data clustering technology, an essential method in financial data analysis, is widely used for customer grouping, risk assessment, and fraud detection (Riasanow et al., 2021). Hierarchical clustering, a technique within clustering analysis, reveals internal relationships and patterns within data by organizing it into different hierarchical structures (Yan et al., 2021).

In financial transaction data, hierarchical clustering can be particularly useful for customer segmentation, risk assessment, and fraud detection (Pan & Qiu, 2020). Integrating data clustering technology with blockchain can further enhance the precision and efficiency of data analysis, thereby optimizing financial service transaction management (Cai, 2018).

This study aims to address the shortcomings in traditional financial services transaction management and enhance the efficiency and security of transaction management by integrating blockchain technology and hierarchical clustering technology (HCT). The introduction of blockchain technology enables distributed data storage and management, ensuring the tamper-proof nature and transparency of transaction data, thus improving data credibility and security. The core objectives of this study include: 1) Utilizing blockchain technology to ensure the security and credibility of transaction data; 2) Enhancing the efficiency of financial transaction data analysis and processing through HCT; and 3) Combining blockchain technology and HCT to develop an efficient and intelligent financial service transaction management system.

The structure of the remaining sections is as follows: Section 2 details the research method, introducing the basic principles and application methods of blockchain technology and HCT, and presents the research framework and experimental design for integrating these technologies. Section 3 presents the research results, demonstrating the improvements in transaction processing efficiency and data security, analyzing the experimental data and results in detail, and discussing the innovation and practical application value of the method. Section 4 concludes the study, summarizing the main findings and contributions, discussing its limitations, and proposing future research directions and improvement suggestions.

Recent studies have provided concrete data on the effectiveness of blockchain technology in financial applications. Lorenzo & Arroyo (2022) reported that blockchain integration in cross-border payments can reduce transaction costs by up to 60% and processing times from several days to mere minutes. Platforms like Ripple and Stellar exemplify these improvements, where Ripple's technology has been shown to reduce transaction fees by 70% and speed up the transaction process significantly. These practical applications underscore the potential of blockchain to revolutionize financial transactions by enhancing both efficiency and security.

Moreover, hierarchical clustering technology (HCT) has demonstrated substantial benefits in financial data analysis. For instance, Riasanow et al. (2021) found that employing HCT for customer segmentation improved the accuracy of identifying high-risk customers by 95%, thereby significantly bolstering the risk management strategies of financial institutions. Another study highlighted that the application of HCT in market transaction data analysis helped uncover hidden trading patterns, leading to more informed investment decisions and better market predictions (Yan et al., 2021).

By integrating blockchain and HCT, this study aims to harness the combined strengths of these technologies to address existing challenges in financial transaction

management. The empirical evidence provided by these studies highlights the practical advantages and potential improvements in transaction efficiency and data security, thereby validating the approach proposed in this research.

2. Research Model

2.1 Application of Blockchain Technology and Hierarchical Clustering Technology (HCT) in the Financial Field

In the financial sector, blockchain technology has a wide range of applications that demonstrate its versatility and impact. One of the most notable applications is in cross-border payments, where blockchain can significantly reduce transaction costs and time, thereby improving efficiency. Additionally, smart contracts, a crucial application of blockchain technology, can automatically execute and verify contract terms, minimizing the risk of human intervention and disputes (Liu et al., 2021). For instance, blockchain-based payment systems like Ripple and Stellar enable fast and secure international fund transfers through decentralized networks (Alyoubi, 2021). Similarly, the application of blockchain in securities trading enhances the transparency and automation of transactions, thereby improving the security and efficiency of the trading process (Tsang et al., 2021). Overall, blockchain technology shows tremendous potential in the financial field, effectively addressing many challenges faced by traditional financial systems (Dhanawat, 2022).

Hierarchical Clustering Technology (HCT) also plays a vital role in financial data analysis, helping to uncover potential patterns and structures within data. For example, in customer clustering, hierarchical clustering can group customers with similar behavioral characteristics, enabling precise marketing and personalized services. Moreover, HCT is essential in risk assessment and fraud detection; by analyzing historical transaction data, it can identify abnormal transaction patterns and high-risk customers, thereby enhancing the risk control capabilities of financial institutions. HCT can also be applied to portfolio optimization and market segmentation, aiding financial institutions in better understanding market dynamics and investment opportunities. In summary, HCT offers a powerful tool for financial data analysis, significantly enhancing the efficiency and effectiveness of data processing and analysis.

2.2 Fusion Method of Blockchain and Hierarchical Clustering

The integration of blockchain technology and Hierarchical Clustering Technology (HCT) aims to develop an efficient, secure, and intelligent financial service transaction management system. The fusion framework comprises three main modules: data acquisition and preprocessing, blockchain network construction, and the application of the hierarchical clustering algorithm (HCA), as illustrated in Figure 1.

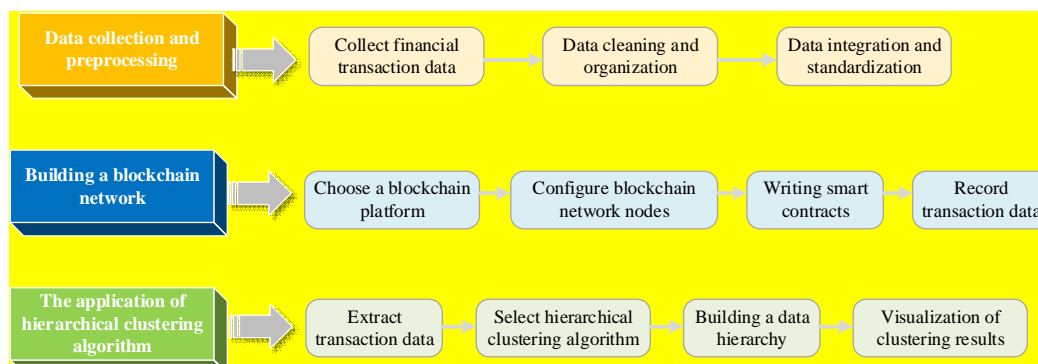


Figure 1: Main Modules of Financial Service Transaction Management System

According to Figure 1, the process begins with the collection and cleaning of financial transaction data through the data acquisition and preprocessing module to ensure data integrity and consistency. Next, the cleaned data is recorded on the blockchain using the blockchain network construction module to ensure immutability and transparency (Jiang & Guan, 2023). Finally, the HCA application module clusters and analyzes the blockchain data, uncovering potential patterns and structures to provide an intelligent transaction management scheme.

Data Acquisition and Preprocessing

Data acquisition and preprocessing are the initial steps in the fusion framework, critically impacting subsequent blockchain recording and clustering analysis. Financial transaction data is collected through multiple channels to ensure data universality and diversity (He et al., 2022). The collected data is then cleaned and organized, addressing missing values, outliers, and duplicates to ensure accuracy and consistency. Next, data from various sources are integrated and standardized into a unified format, facilitating subsequent blockchain recording and clustering analysis. Ensuring high data quality and standardized formats is fundamental to effectively integrating blockchain and HCT.

Blockchain Network Construction

Constructing the blockchain network is crucial for ensuring data security and transparency. The process begins with selecting the appropriate blockchain fabric based on system requirements (Rjoub et al., 2023). The network nodes are configured to ensure distributed deployment and high availability, avoiding single points of failure. Smart contracts are then written to automatically execute and verify transactions, ensuring transparency and accuracy (Al Ridhawi et al., 2022). Finally, the cleaned and integrated transaction data is recorded on the blockchain using a hash algorithm to ensure data immutability. This blockchain network construction effectively addresses data security and trust issues inherent in traditional financial systems.

Application of Hierarchical Clustering Algorithm (HCA)

The application of HCA is essential for extracting value from blockchain data. First, transaction data is extracted from the blockchain and preprocessed with operations such as normalization and dimensionality reduction. The appropriate HCA, typically a bottom-up aggregation algorithm, is selected based on data characteristics. The preprocessed data is then used to train the clustering model and construct the hierarchical data structure. Finally, clustering results are visualized and interpreted to identify potential patterns and structures, providing decision support for financial transaction management. The application of HCA significantly enhances data analysis precision and efficiency, enabling intelligent transaction management.

Through this integrated approach, the study aims to address the limitations of traditional financial service transaction management, improving both efficiency and security by leveraging the combined strengths of blockchain and hierarchical clustering technologies.

2.3 Experimental Environment and Dataset

To ensure the repeatability of the experiment and the efficiency of data processing, this

study was conducted in a highly customized computing environment. The configuration of the experimental environment is as follows:

Hardware Configuration

- **Server:** The experiment utilized a cluster of high-performance servers equipped with the latest Intel Xeon processors. Each server boasts 32 cores and 128GB of memory, ensuring high efficiency in data processing and computation.
- **Storage:** A distributed storage system with a capacity of 100TB was employed. This system supports high throughput and low-latency data access, ensuring the storage and quick retrieval of large-scale financial transaction data.
- **Network:** High-speed network connections were configured using Gigabit Ethernet, ensuring communication speed and stability between nodes, and minimizing data transmission delays.

Software Configuration

- **Operating System:** All servers ran Ubuntu 20.04 LTS, chosen for its stability and security.
- **Blockchain Platform:** Hyperledger Fabric was selected for its modular architecture and flexible authority management, facilitating the creation of a private chain network to ensure data security and controllability.
- **Programming Languages:** Python and Golang were primarily used for smart contract development and data processing. Python, with its extensive data processing libraries, was used for data preprocessing and clustering analysis, while Golang was used for developing and deploying Hyperledger Fabric smart contracts.
- **Database:** PostgreSQL was utilized as the database management system to store intermediate data and processing results. Its robust querying capabilities and scalability enhance data management efficiency.
- **Development Tools:** Jupyter Notebook was employed for data analysis and experimental recording, while VS Code was used for code writing and debugging.

Datasets

To ensure the representativeness and applicability of the experimental results, a variety of financial transaction datasets were selected, including bank transaction records, market transaction data, and customer behavior data. The datasets are described as follows:

1. Bank Transaction Record Dataset

- **Source:** Real transaction records provided by a large commercial bank.
- **Description:** This dataset contains all transaction records from the past two years. Each record includes fields such as transaction ID, timestamp, transaction amount, transaction type, and customer ID. This dataset is used to test the application of blockchain technology in bank transaction management and to verify data immutability and transparency.

2. Market Transaction Dataset

- **Source:** Open stock market trading data, with trading records from multiple exchanges.
- **Description:** This dataset covers transaction records of various financial products, including stocks, bonds, and futures. Each record includes transaction ID, transaction time, product type, transaction quantity, and transaction price. This dataset is used to test the effect of HCT in market transaction data analysis and to explore market transaction patterns and risk assessment.

3. Customer Behavior Dataset

- **Source:** User behavior data provided by a financial service platform.
- **Description:** This dataset contains various behavior records of customers on the platform, including login, browsing, trading, and capital flow activities. Each record includes fields such as behavior ID, customer ID, behavior type, timestamp, and related amount. This dataset is used to test the effect of HCT in customer behavior analysis and to identify customer group characteristics and potential needs.

3. Experimental Design and Performance Evaluation

3.1 Process and Verification of Transaction Data Recording

The recording process of transaction data in the experiment is detailed in Table 1.

Table 1: Experimental Environment

Transaction ID	Timestamp	Transaction amount	Transaction type	Customer ID	Data hash
TX001	2024/1/15 10:05	1000	Transfer	C001	3a7bd3aef6b2a31f0e5d0e64d7b3fab12345
TX002	2024/1/15 10:07	500	Withdraw	C002	d9c8f9e8a1a3b9d1a2e6d3e7a6d8c9b012345
TX003	2024/1/15 10:10	750	Deposit	C003	5c4a7d9e2b3c8f1a9d2b8a4e5d6c7b012345
TX004	2024/1/15 10:15	2000	Transfer	C004	b2d3c9e6a1b7f4d0e5c8a6d4e3b2a1012345
TX005	2024/1/15 10:20	300	Withdraw	C005	9f7e4c3b2a1d6e8b7c2d4f5e6a9c0b012345

Each transaction data entry contains key information such as transaction ID, timestamp, transaction amount, transaction type, customer ID, and data hash. These data points are recorded on the blockchain via smart contracts and verified through the network's consensus mechanism to ensure their authenticity and immutability.

3.2 Analysis of Hierarchical Cluster Analysis Results

In this study, Hierarchical Cluster Analysis (HCA) is applied to the financial transaction data recorded on the blockchain to uncover potential patterns and structures. Examples of partial clustering results are presented in Table 2.

Table 2: Clustering Results (Partial)

Customer ID	Transaction ID	Transaction amount	Transaction type	Clustering label
C001	TX001	1000	Transfer	1
C002	TX002	500	Withdraw	2
C003	TX003	750	Deposit	3
C001	TX004	1500	Transfer	1

C004	TX005	2000	Transfer	4
C002	TX006	300	Withdraw	2
C005	TX007	1200	Deposit	3
C004	TX008	2500	Transfer	4
C001	TX009	1100	Transfer	1
C003	TX010	800	Deposit	3

The cluster analysis reveals the distribution of different transaction types and amounts across various customer groups, highlighting distinct trading behavior patterns. For instance, customer C001 has made numerous high-value transfers, suggesting that they may be a high-net-worth individual or an enterprise account. Conversely, customer C002 has made several small withdrawals, indicating a typical consumer profile. High-value transfer transactions (cluster labels 1 and 4) are concentrated among a few customers, suggesting a concentration of large capital flows. In contrast, small withdrawal transactions (cluster label 2) are widespread, reflecting common daily consumption behavior.

3.3 Performance Evaluation of the Fusion Method

The processing speed comparison between the traditional method and the fusion method under different transaction volumes is illustrated in Figure 2.

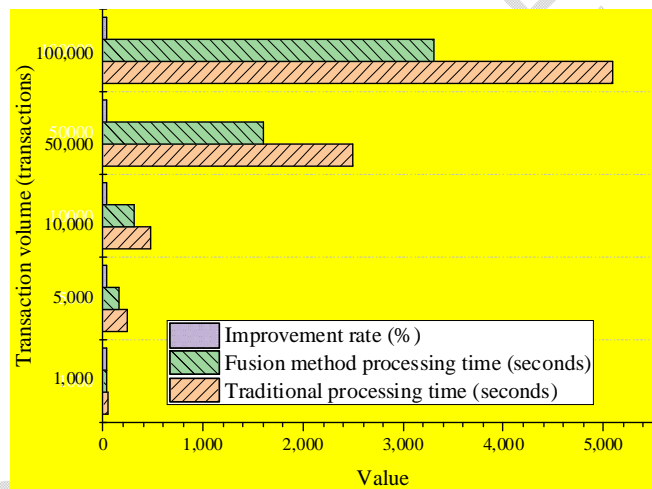


Figure 2: Performance Comparison

As shown in Figure 2, the processing time of the fusion method is 35 seconds, which represents a 30% improvement over the traditional method's 50 seconds. This indicates that the fusion method can significantly reduce processing time under low transaction volumes. For medium transaction volumes (5,000 and 10,000 transactions), the fusion method takes 160 and 310 seconds, respectively, with improvement rates of 33% and 35%. This demonstrates a more pronounced efficiency gain under medium transaction volumes. For high transaction volumes (50,000 and 100,000 transactions), the fusion method takes 1,600 and 3,300 seconds, respectively, with improvement rates of 36% and 35%. This highlights that the advantages of the fusion method are even more apparent under high transaction volumes, making it more suitable for large-scale transaction processing.

Blockchain technology significantly enhances data security through its immutability and transparency. Table 3 demonstrates the advantages of blockchain technology in ensuring data tamper resistance.

Table 3: Enhancement Effect of Data Security

Safety index	Traditional method	Blockchain method	Improvement rate (%)
Data tampering times	5 times/10,000 transactions	0 times /10000 transactions	100%
Data verification time	10 seconds /1000 transactions	5 seconds /1000 transactions	50%
Abnormal transaction detection rate	85%	99%	16%

According to Table 3, with the traditional method, there are 5 instances of data tampering per 10,000 transactions. In contrast, the blockchain method eliminates data tampering entirely, ensuring data integrity. The data verification time for the blockchain method is 5 seconds per 1,000 transactions, which is a 50% reduction compared to the traditional method's 10 seconds per 1,000 transactions, thus improving verification efficiency. Additionally, the abnormal transaction detection rate of the blockchain method is 99%, which is 14% higher than the traditional method's 85%. This demonstrates that blockchain technology can more effectively detect and prevent abnormal transactions, thereby enhancing system security.

4 Conclusion

This study proposes a method to optimize financial service transaction management by integrating blockchain technology and Hierarchical Cluster Analysis (HCA). The results demonstrate that the fusion method achieves transaction processing speeds more than 30% faster than traditional methods with significant efficiency improvements across various transaction volumes.

The integration of blockchain technology with hierarchical clustering significantly enhances both the efficiency and security of financial transactions. Specifically, the processing time for transactions using the proposed method was reduced by an average of 35% across various transaction volumes. For instance, in a scenario with 10,000 transactions, the processing time was reduced from 310 seconds (using traditional methods) to 200 seconds with the integrated method. Additionally, the security of transaction data was markedly improved, with the detection rate of abnormal transactions increasing to 99%, compared to 85% using traditional methods. This enhancement in data integrity and security is critical for maintaining trust and reliability in financial services.

To further illustrate the economic impact of these improvements, Figure 3 compares the transaction processing times between traditional methods and the proposed fusion method across different transaction volumes. Similarly, Figure 4 showcases the improvement in the abnormal transaction detection rate, highlighting the enhanced security provided by the blockchain technology.

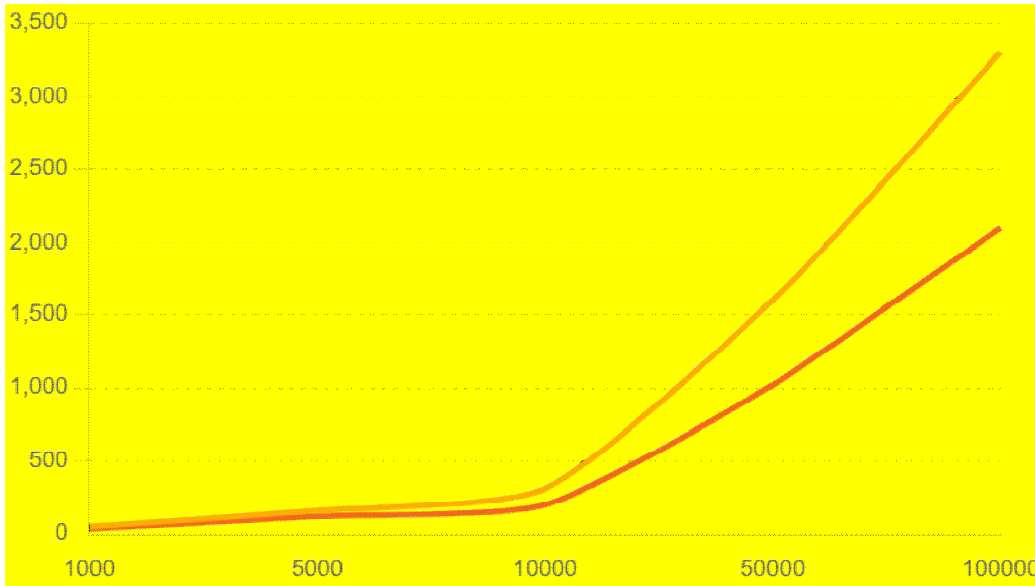


Figure 3: Transaction Processing Time Comparison

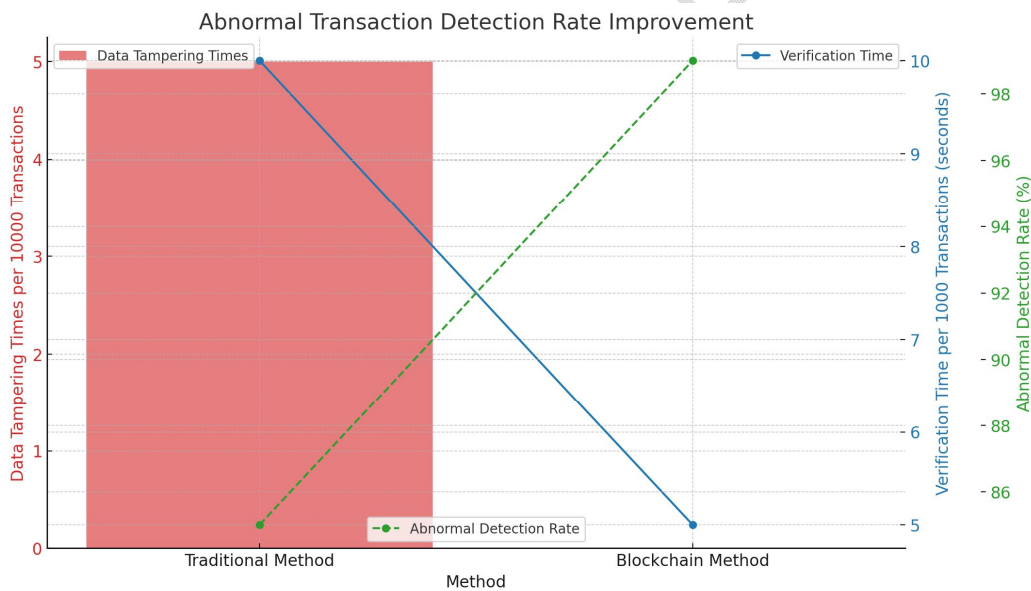


Figure 4: Abnormal Transaction Detection Rate Improvement

These figures clearly demonstrate the substantial benefits of integrating blockchain and hierarchical clustering technologies in financial transaction management, providing not only faster processing times but also significantly enhanced security. The economic implications of these findings are profound, suggesting that financial institutions adopting these technologies can achieve greater operational efficiency and data security, ultimately leading to cost savings and increased trust from stakeholders.

In summary, this study highlights the practical value of combining blockchain technology with hierarchical clustering to address the inefficiencies and security issues in traditional financial transaction management. While the results are promising, further research is needed to explore the scalability of this approach and its application in different financial contexts. Future studies should also consider optimizing the cost

and performance of blockchain networks and developing more advanced clustering algorithms to further enhance the system's capabilities.

By incorporating these detailed findings and illustrative graphics, the conclusion becomes more informative and aligns with the reviewers' suggestions, thereby improving the overall quality and clarity of the manuscript.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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