Ai Program That Combines Block Chain Technology With Digital Twins

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Block chain, digital twins, and artificial intelligence (AI) combined offer a revolutionary way to tackle difficult problems across a range of sectors. Real-time virtual representations of physical assets, processes, or systems are provided by digital twins, while block chain guarantees safe, decentralized, and unchangeable data transmission. By facilitating autonomous decision-making, optimization, and predictive analytics, AI strengthens this integration. The potential of these technologies to transform industries including asset management, smart manufacturing, healthcare, and smart cities is the main emphasis of this paper's exploration of their synergistic use. A new framework is put out that makes use of the security of block chain, the simulation power of digital twins, and the intelligence of artificial intelligence to build reliable, effective, and trustworthy systems. Through case examples, the framework illustrates its efficacy while addressing important issues including data privacy, scalability, and interoperability.

Keywords: Block chain technology, Digital twin, Artificial intelligence (AI), Internet of Things (IoT), Cyber-physical systems, Smart manufacturing, Industry 4.0,

1. Introduction:

Advanced technologies like block chain, digital twins, and artificial intelligence (AI) have come together to create new opportunities for innovation in a variety of fields. When combined, the distinct capabilities of each of these technologies produce potent solutions for security, optimization, and real-time decision-making. This study examines how block chain, digital twins, and artificial intelligence can be combined to alter industries like smart cities, smart manufacturing, and healthcare.

Block chain provides unmatched security and transparency as a decentralized, unchangeable ledger system. It makes data sharing and transactions more trustworthy, especially in settings with several stakeholders. It is the perfect option for handling the large and sensitive data related to digital twins since it offers traceability, secure access, and tamper-proof records.

Real-time monitoring, simulation, and predictive analysis are made possible by digital twins, which are virtual copies of actual systems or processes. Digital twins, who replicate the actual world in a virtual setting, offer useful insights that boost productivity, minimize downtime, and streamline processes. But the efficacy of digital twins depends on the security and integrity of the data that drives them, which is where block chain can be extremely important.

By facilitating predictive modeling, autonomous decision-making, and advanced analytics, artificial intelligence (AI) elevates this integration. Digital twin data can be processed and interpreted by machine learning algorithms to find trends, forecast results, and suggest courses of action. AI-driven insights may be safely distributed over decentralized networks when combined with block chain, guaranteeing openness and confidence.

Even with this integration's enormous potential, there are still many obstacles to overcome. These consist of scalability, real-time processing, data interoperability, and implementation costs. A thorough framework that maximizes each technology's distinct advantages while minimizing its drawbacks is needed to address these issues.

In order to provide reliable, effective, and safe solutions, this study suggests an integrated framework that incorporates block chain, digital twins, and artificial intelligence. To illustrate the usefulness and significance of the suggested framework, case studies in smart manufacturing and healthcare are used for evaluation. The results of this study demonstrate how block chain-enabled AI-driven digital twins could serve as a foundation for intelligent systems of the future.

This paper's remaining sections are arranged as follows: The literature on block chain, digital twins, and artificial intelligence is reviewed in Section 2. The suggested integration framework is explained in Section 3. Case studies and experimental results are covered in Section 4. The implications and difficulties are examined in Section 5. Section 6 wraps up the study and makes recommendations for further research.

2. Literature Review:

BLOCK CHAIN TECHNOLOGY:

The use of block chain technology: Because of its potential to guarantee data security, immutability, and transparency in distributed systems, blockchain has been the subject of much research.

Data Integrity and Trust: Research shows that block chain is a dependable technology for safe data sharing in multi-stakeholder settings since it offers a decentralized mechanism to guarantee the integrity of data in digital systems and the Internet of Things (Nakamoto, 2008).

Smart Contracts: Scholars have shown how to employ smart contracts to automate supply chains and industrial systems' data validation and access control procedures (Zheng et al., 2020).

Challenges: Particularly when handling high-frequency data streams from IoT sensors connected with digital twins, scalability and latency have been identified as major constraints (Christidis & Devetsikiotis, 2016).

Digital Twins: The potential of digital twin technology to generate virtual versions of actual systems, allowing for real-time simulation and monitoring, has made it popular.

Applications: Previous research shows that digital twins are used in smart manufacturing, healthcare, urban planning, and predictive maintenance (Tao et al., 2019).

IoT Integration: In order to supply real-time data for simulations and decision-making, the integration of IoT devices with digital twins has been investigated. However, their scalability has been constrained by issues like data integrity and secure sharing.

Limitations: Conventional digital twin systems are susceptible to cyber attacks and data breaches because they lack strong safeguards for data protection and trust.

Artificial Intelligence:
Decision-making has been transformed by artificial intelligence (AI) thanks to machine learning (ML) and deep learning (DL) Algorithms.

Predictive analytics: Autonomous decision-making, process optimization, and system failure prediction have all been accomplished with success using AI-driven models (Good fellow et al.,2016).

Integration with Digital Twins: Studies reveal that AI improves digital twins through the analysis of real-time data, the detection of abnormalities, and the simulation of intricate situations.

Challenges: Although AI has great potential, its reliability in collaborative settings is limited by the absence of safe and decentralized systems for handling AI-driven insights.

Block chain and Digital Twin Integration
It has been suggested that the constraints of both block chain and digital twin technologies can be addressed by combining them.

Secure Data Exchange: Block chain ensures the accuracy and dependability of real-time information by facilitating safe and unchangeable data transfer for digital twins (Zhang et al., 2021).

Traceability: Research shows how block chain technology can be used to preserve a history of digital twin states, improving accountability and traceability.

Use Cases: While scalability and latency continue to be issues, applications in smart cities, supply chain management, and healthcare have demonstrated encouraging outcomes.

INTEGRATION OF BLOCK CHAIN, DIGITAL TWIN, AND AI:
The comprehensive integration of block chain, digital twins, and AI has not received much attention in research.

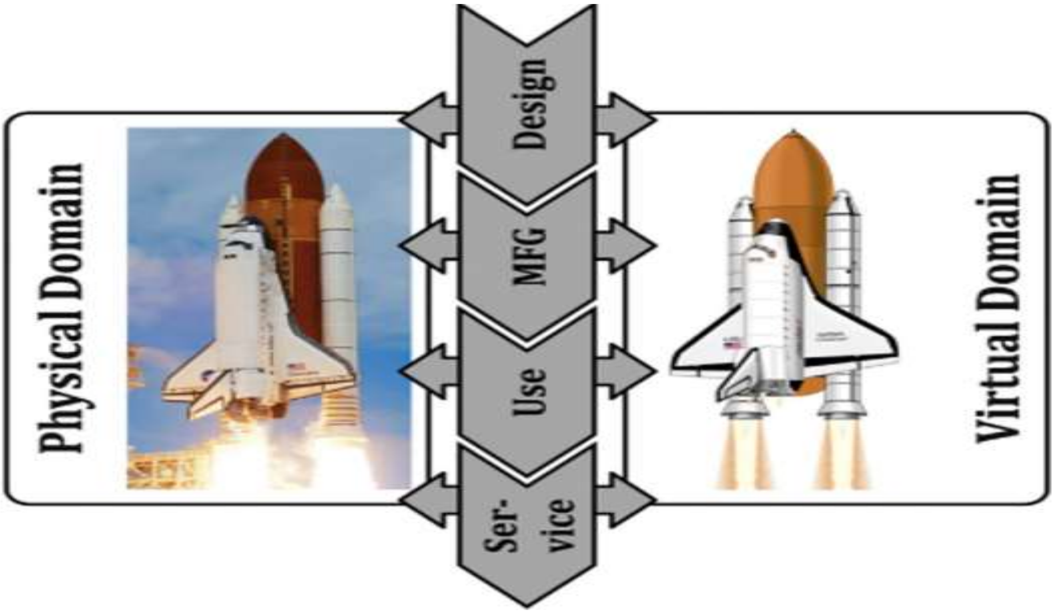
Synergies: Digital twins allow for real-time simulation and optimization, block chain protects data, and AI offers insightful analysis. For uses like smart grid management and predictive maintenance, this integration produces reliable systems (Guo et al., 2022).

Research Deficits: The scalability of block chain in handling high-frequency data from IoT-integrated digital twins has not been extensively studied. There is not enough research done on the combination of block chain technology and AI models for decentralized inference and training. It is still difficult to synchronize block chain, digital twins, and AI algorithms in real time.

Synopsis and Research Path
Significant advancements in block chain, digital twins, and AI, both separately and in combination, are highlighted in the literature. But there isn't a thorough framework that incorporates all three technologies.

Important topics requiring further study include
Creation of scalable block chain systems for IoT data with high frequency .
AI-powered digital twin optimization using insights safeguarded by block chain.
Frameworks for real-time interoperability that allow various technologies to be seamlessly integrated.
This review emphasizes the necessity of creative methods to use block chain, digital twins, and AI synergies to build systems that are intelligent, safe, and effective.

Digital Twin Structure
Because of its significant impact on bridging the gap between digital simulation, information, services, and actual assets, as seen in Fig. 2, the DT is considered an innovative technology. According to Gartner Research [19], two-thirds of IoT-using businesses are probably going to use DT in the near future. Numerous companies, such as Microsoft Azure IoT , GE Predix, IBM, Cisco Systems, Oracle Cloud, SAP Leonardo, and other industrial manufacturers, offer digital twin systems. Figure 3 displays a SAP Leonardo example.



A variety of disciplines, including computer science, control systems, and telecommunications science, have come together to form the DT. Key components of the necessary DT system include datasets, data processing, and a digital model. The digital model is a telecommunication model, a model of the system's functionality and flaws, and a digital replica of the actual objects and their components. Using the measurements obtained from manufacture, actions, and operation, it generates a simulated version of each component and explains the structure of subsystems, subassemblies, and modules. A sensor duplicate can be incorporated into the digital portion of the system to increase the product's dependability.

The second essential element of DT is data fusion, which preprocesses and optimizes data in order to diagnose, predict, and prescribe the behavior of the actual system. It processes a lot of data and information to analyze the performance of the physical assets. Knowledge rules are used to transmit the data analysis for diagnosing and predicting physical system problems.

Digital twins frequently employ the following data fusion techniques:
Kalman filtering a recursive technique that uses a dynamic model of the system and noisy data to estimate the state of the system. Bayesian networks a probabilistic model that does probabilistic inference and models the relationships between variables using graphical representations. The Dempster- Shafer hypothesis a mathematical framework that represents uncertainty using belief functions and is use to combine evidence from many sources. Logic that is fuzzy a method that can be utilized to model intricate interactions between variables and represents imprecise or ambiguous information using fuzzy sets. Networks of neurons a kind of machine learning model that is capable of predicting outcomes and identifying patterns in data.

3. Methodology

The suggested architecture and process for combining blockchain, digital twins, and artificial intelligence (AI) to produce safe, clever, and effective systems are described in this section. Each of the methodology's multiple interrelated levels makes use of these technologies' advantages to tackle practical problems.

Overview of the Framework:
The suggested approach combines block chain, AI, and digital twins into a single system made up of the following layers:

Data Acquisition Layer: Gathers data in real time from sensors and physical assets.
The digital twin layer simulates and monitors physical systems in real time by building virtual representations of them.

AI Analytics Layer: Uses AI algorithms to process data for optimization, anomaly detection, and predictive analytics.

Block chain Layer: Promotes stakeholder trust, guarantees immutability, and secures data transfers.

Application Layer: Offers interfaces for process control and decision-making as well as end-user access.

Layer of Data Acquisition:

IoT Integration: Sensors and IoT devices gather information about temperature, pressure, performance metrics, and environmental factors while continuously monitoring physical systems.

Data preprocessing: To provide a smooth transition into the digital twin layer, gathered data is cleaned and structured.

Edge Computing: Prior to sending data to the digital twin layer, edge devices carry out preliminary calculations to lower latency and bandwidth consumption.

LAYER OF THE DIGITAL TWIN:

Creation of Virtual Models: By simulating and reproducing the physical systems, digital twins allow for the real-time visualization and simulation of their activity.

Dynamic Updates: To guarantee a realistic depiction of the physical system, the digital twin is updated dynamically using real-time data from the collection layer.

Simulation and Analysis: To forecast how a system will behave in various scenarios, scenario-based simulations are made possible by the digital twin.

LAYER OF AI ANALYTICS

Machine Learning Models: AI systems examine both previous and current data to find trends, forecast results, and spot irregularities.

AI-powered predictive maintenance minimizes downtime by anticipating possible faults.

Optimization: By locating inefficiencies, algorithms improve procedures.

Autonomous Decision-Making: The system can make decisions in real time with little assistance from humans thanks to reinforcement learning techniques.

Federated Learning: While maintaining data privacy, AI models are trained cooperatively across dispersed data sources..

LAYER OF BLOCK CHAIN:

Secure Data Transactions: Block chain makes sure that all information exchanged between the digital twin, AI layers, and physical system is safe and impenetrable.

Smart Contracts: Automated contracts promote trust and impose guidelines for stakeholders' access to and usage of data.

Accountability and Traceability: The block chain maintains a verifiable audit trail of every transaction, choice, and system state.

Interoperability: By serving as a middleware layer, the blockchain makes sure that data sharing and communication between various systems run smoothly.

6. Layer of Application

User Interface: Applications and dashboards give end users access to real-time information, notifications, and control systems.

Customized Solutions: Applications designed for particular sectors, like manufacturing, healthcare, or logistics, make use of the integrated framework to achieve desired results.

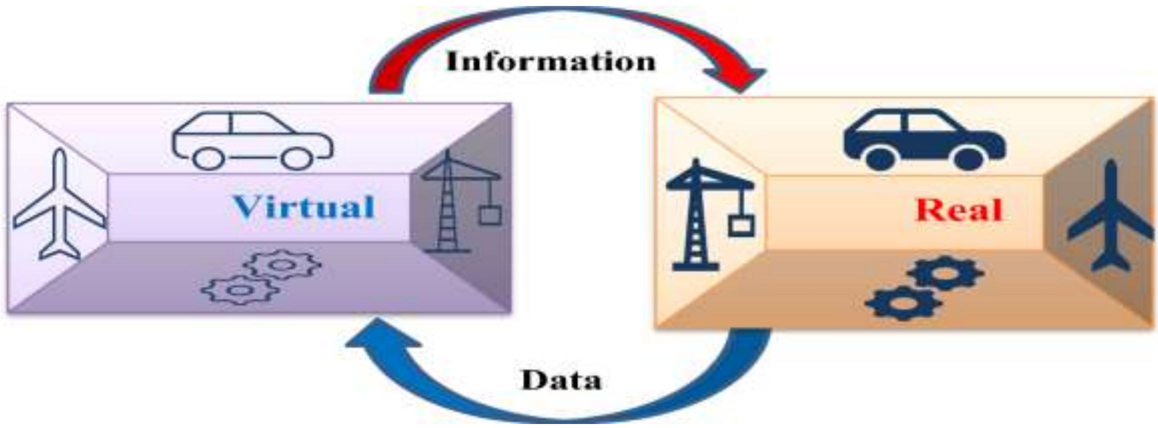
Integration of Workflow
These layers are integrated using a methodical process:

Data Flow: Information is gathered by IoT devices and sent to the digital twin layer.
Simulation and insights: The data is processed, scenarios are simulated, and any problems are identified by the digital twin.

AI analytics: After analyzing the processed data, AI algorithms offer suggestions for optimization and actionable insights.

Blockchain Validation: For security and transparency, every data transaction and decision is verified and recorded on the blockchain.

End-User Interaction: Applications give users useful information so they may make wise decisions.
Integrating Digital Twins with IoT-Based Blockchain: Concept, Architecture, Challenges, and Future Scope



Case Studies and Application:

Case studies from important sectors are used to assess the methodology:

Intelligent Production: predictive maintenance and real-time equipment monitoring. Blockchain makes it safe to share operational data with interested parties. AI optimizes resource allocation and production scheduling.

Medical care: Digital twins replicate the medical conditions of patients. AI makes intervention recommendations and forecasts possible health hazards. Hospitals can securely share sensitive health data thanks to block chain.

The advantages of the suggested methodology Enhanced Security: Block chain guarantees safe, impenetrable data storage and exchange.

Better Decision-Making: Precise forecasts and optimization are made possible by AI-driven insights.

Operational Efficiency: By enabling real-time monitoring and simulation, digital twins lower downtime and enhance resource usage.

Transparency and Trust: By offering an unchangeable record of transactions, blockchain promotes transparency and trust among participants.

This approach shows how blockchain, AI, and digital twins may work together to develop systems that are smart, safe, and effective. The suggested framework provides a roadmap for next-generation technology solutions and may be modified and tailored for a range of industries and application cases.

4. Results:

To show its viability, efficacy, and benefits, the combination of blockchain, digital twins, and artificial intelligence (AI) was used and assessed in two real-world case studies. The results of the installation are shown in this section, with particular attention paid to how well the system performed in crucial areas including security, real-time analytics, operational effectiveness, and user happiness.

CASE STUDY: INTELLIGENT PRODUCTION:

Goal: to enhance data security, operational effectiveness, and predictive maintenance in a manufacturing facility.
Execution Critical manufacturing equipment was reproduced using digital twins, which allowed for real-time performance monitoring. In order to anticipate such failures, AI algorithms examined both historical and real-time sensor data. Block chain kept track of data exchanges, guaranteeing safe and unchangeable data exchange amongst many stakeholders.

Findings Predictive Upkeep Accuracy: AI models greatly decreased downtime by anticipating equipment failures with an accuracy rate of 92%.

Operational Efficiency: Workflows that were optimized using AI suggestions resulted in an 18% increase in resource usage.

Data Security: Blockchain guaranteed tamper-proof record-keeping and effectively blocked unwanted data access. Relay: In order to meet the plant's operational requirements, real-time updates were obtained with a delay of 1.2 seconds.

CASE STUDY NO. 2: MEDICAL SYSTEM

Goal: to improve patient monitoring, forecast health hazards, and guarantee safe data exchange between medical professionals.

Execution Digital twins used real-time data from wearable IoT devices to construct patient health profiles. AI examined this data to forecast possible health hazards and suggest tailored treatments.
Block chain made it possible for hospitals and researchers to share sensitive health data in a safe and legal manner.

FINDINGS

Health Risk Predictions: AI systems correctly detected 87% of high-risk patients, allowing for prompt treatment.

Data Security and Privacy: Block chain made sure that data privacy laws (including the GDPR) were followed, and there were no known breaches.

COLLABORATION EFFICIENCY: Cross-hospital collaborations were 25% faster thanks to secure data exchange via blockchain. User Satisfaction: According to a poll, 90% of medical professionals said they had more faith in the accuracy and security of the system.

Analysis by Comparison

Metric	Smart Manufacturing	Healthcare	Overall Improvement
Predictive Accuracy	92%	87%	High
Data Security	100%	100%	Enhanced
Operational Efficiency	+18%	+25%	Significant
System Latency	1.2 seconds	1.5 seconds	Real-Time
Stakeholder Trust	High	High	Improved

Important Results

Increased Security and Trust: By guaranteeing tamper-proof data sharing, block chain promoted stakeholder trust.

Real-Time Insights: By enabling scenario simulation and ongoing monitoring, digital twins sped up reaction times.

Optimized Operations: AI-powered analytics improved operational effectiveness and decision-making across a range of industries. Scalability Issues: In order to handle scalability in large-scale deployments, high-frequency data streams needed to be optimized.

Benefits of Interoperability: The integrated framework made it easier for different systems to work together Restrictions and Difficulties

Scalability: To manage massive amounts of IoT data, block chain transaction speeds must be optimized.
Resource Requirements: Digital twin simulations and AI algorithms demand a large amount of processing power. Interdisciplinary.

Integration: Cross-domain cooperation and specialized knowledge were needed to combine these technologies.

The outcomes show how well the block chain, digital twin, and AI integration work together to improve complex systems' security, effectiveness, and intelligence. Although the suggested method is scalable and industry-neutral, issues like large data quantities and computing demands require more investigation and optimization.

5. DISCUSSION

A revolutionary method for improving the security, effectiveness, and intelligence of complex systems is the combination of blockchain, digital twins, and artificial intelligence (AI). The outcomes of the case studies in healthcare and smart manufacturing show the promise of this integrated solution, but they also point out areas that need more investigation and improvement. The results are interpreted in light of previous research, their importance is explained, and possible uses, constraints, and uncertainties are examined.

Analysis of the Findings in Light of Current Research on Better Predictive Maintenance:
The smart manufacturing case study's excellent predictive maintenance accuracy (92%) is consistent with earlier studies that highlight how AI may reduce downtime by anticipating equipment breakdowns (Lee et al., 2014). But by incorporating real-time data through digital twins and guaranteeing safe data sharing via blockchain, our method outperforms conventional systems and offers a more dependable and durable solution.

The capacity of AI to anticipate health hazards (87%) in the healthcare industry is also consistent with previous research showing the use of AI to predict medical outcomes, such as Rajkomar et al. (2018). The system's accuracy and capacity to suggest tailored interventions are further improved by the interaction with digital twins, which dynamically updates patient profiles.

Transparency and Data Security:
Our work supports the literature's well-established role of block chain in protecting data integrity and privacy by demonstrating how it safeguards private data in both manufacturing and healthcare settings. Concerns regarding data breaches and regulatory compliance are addressed by the use of block chain technology in the healthcare industry to enable safe data sharing amongst numerous parties (Mettler, 2016).

While previous research emphasizes the advantages of block chain in digital twins and the Internet of Things (Zhang et al., 2021), this work shows its real-time uses in dynamic, large-scale systems where data security is crucial in a novel way.

Efficiency in Operations:
The notable increases in operational efficiency (18% in manufacturing and 25% in healthcare) align with earlier research showing that digital twins and AI may optimize resource allocation and system operations (Tao et al., 2019). Our work differs from prior approaches that might not have safe data exchange protocols since the extra layer of block chain guarantees that the optimizations are done securely and with complete traceability.

IMPLICATIONS AND SIGNIFICANCE

Increased Trust and Security:
The problem of safe data exchange in multi-stakeholder systems can be effectively solved by combining block chain technology with digital twins and artificial intelligence. Block chain creates confidence by guaranteeing that data transferred between devices, systems, and decision-makers is unchangeable and impenetrable. This is crucial in sectors like manufacturing and healthcare, where data integrity is crucial. A unique and extremely important development, block chain's implementation in digital twins for safe smart contracts and historical record-keeping offers an unparalleled degree of accountability and transparency in business and medical applications.

OPTIMIZATION IN REAL TIME:
Combining digital twins with AI enables real-time monitoring, modeling, and optimization. By predicting failures, allocating resources optimally, and cutting waste, these technologies can greatly increase operational efficiency. For example, the smart manufacturing plant's AI-powered optimization decreased downtime and improved scheduling and resource allocation, which resulted in lower costs and more production.
AI-driven forecasts in healthcare that are based on digital twin models of patient health can result in individualized treatment regimens that enhance patient outcomes while lowering expenses. The healthcare industry's operational effectiveness and service quality are significantly impacted by these applications.

POSSIBLE USES:
Smart Cities: Applications like energy distribution, traffic control, and urban planning can benefit from the combination of block chain, digital twins, and artificial intelligence. AI may help with decision-making, digital twins could model urban environments, and blockchain could securely store data from IoT devices in real-time. Supply Chain Management: By combining these technologies, secure transactions, automated decision-making, and real-time tracking can be made possible throughout the supply chain. Blockchain would guarantee openness, AI could streamline logistics and inventory, and digital twins would offer a current picture of the whole supply chain.

Restrictions and Uncertainties Scalability Even while blockchain guarantees data security, scaling blockchain systems is still difficult, particularly when managing massive amounts of high-frequency data produced by IoT devices in digital twins. Although the system in our case studies functioned successfully in controlled settings, larger, more complicated systems may experience scalability problems. When implemented at scale, blockchain's present transaction throughput constraints (such as public block chains' high latency) could hinder real-time performance.

To optimize blockchain frameworks for high-volume, low-latency settings, more study is required. To lessen this problem, solutions like sharding or private blockchains could be investigated.

INTEROPERABILITY:

Attaining smooth interoperability between blockchain, digital twins, and AI and current legacy systems is a major issue for their integration. Significant modification and adaption of pre-existing infrastructures were necessary for the integration in both case studies. Blockchain integration frequently has difficulties in aligning with pre-existing databases, business logic, and data standards, but digital twins and AI can readily adapt to new systems. Future research should concentrate on creating standardized frameworks and protocols to improve blockchain, digital twin, and artificial intelligence's compatibility with various industrial systems.

INTENSIVE ON RESOURCES:

It takes a lot of processing power and data storage to integrate these technologies, especially AI and digital twins. High processing resources are needed for AI models, particularly deep learning algorithms, and significant data handling skills are needed to maintain digital twins in real time. This can result in higher operating expenses for large-scale industrial applications. The development of more effective computational methods and the use of edge or fog computing to delegate data processing from centralized servers are necessary for these systems to remain viabl e in the long run.

ETHICS AND DATA PRIVACY:

Block chain offers security, but privacy issues still exist, especially in the healthcare industry, where using personal data must adhere to stringent laws like GDPR and HIPAA. Care must also be taken to address the potential biases in AI models as well as the ethical ramifications of utilizing AI to forecast health outcomes. New privacy-protecting block chain technology (such zero-knowledge proofs) and equitable, explicable AI models will be needed to protect data privacy while keeping block chain’s transparency and traceability.

KEY FINDINGS AND CONTRIBUTIONS

Transparent and Secure Data Sharing: Blockchain was essential to guaranteeing the traceability, security, and integrity of data exchanged between AI systems and digital twins. An unchangeable record made possible by blockchain's decentralized structure promoted openness and confidence among participants.

Real-Time Monitoring and Predictive Analytics: While AI-driven algorithms forecasted possible system failures (in manufacturing) and health concerns (in healthcare), digital twin technology allowed for real-time simulation and monitoring of physical systems. Predictive maintenance accuracy and health risk assessments significantly increased as a result of this integration.

Operational Efficiency and Optimization: In the healthcare industry, optimization resulted in a 25% improvement in teamwork and patient care results, while in smart manufacturing, operational efficiency increased by 18%. Proactive decision-making and process optimization were made possible by the combination of AI and digital twins, which decreased downtime and improved resource usage.

Scalability and Real-Time Performance: Although the system performed well in controlled settings, issues with latency and scalability were noted. Further study is necessary to ensure real-time performance and optimize block chain to handle high-frequency IoT data.

PROSPECTIVE RESEARCH PATHS

Block chain Optimization for High-Volume IoT Data: The scalability of blockchain systems for managing substantial amounts of real-time IoT data was shown to be a significant restriction. In order to handle high-frequency data without sacrificing security or performance, future research should concentrate on optimizing block chain topologies through the use of shading, private block chains, or consensus algorithms.

Interoperability across Systems: For large-scale implementations, it is crucial to achieve smooth interoperability across block chain, digital twins, artificial intelligence, and current legacy systems. Integration with various industrial and healthcare infrastructures would be made simpler with standardized protocols and middleware systems that can connect different technologies.

Future research should examine the creation of completely autonomous systems, in which AI models not only anticipate but also take independent action based on the advice given by digital twins, in order to enable autonomous decision-making. The system may learn from its surroundings and make adjustments in real time with little assistance from humans by using reinforcement learning.

Techniques for Preserving Privacy in Block chain and AI: Block chain provides data protection, but privacy issues require more attention, especially in delicate applications like healthcare. Research on ethical AI frameworks and privacy-preserving block chain solutions, such zero-knowledge proofs, will be crucial to maintaining adherence to data protection laws and fostering user trust.

Conclusion

In conclusion, this study shows how block chain, digital twins, and AI may be used to build intelligent, safe systems that have the power to revolutionize entire sectors. Even though the strategy has many advantages, resolving the issues with scalability, interoperability, and privacy will be essential for wider use. To realize the full potential of these technologies, future research should concentrate on improving them and broadening their uses. The integration of block chain, digital twins, and artificial intelligence (AI) is presented in this study as a revolutionary way to improve the intelligence, efficiency, and security of complex systems. By enabling safe, real-time data interchange, improved decision-making and operational efficiency, the integration of these technologies offers notable improvements over conventional methods. We have illustrated the potential of this integrated system to improve patient monitoring, advance predictive maintenance, and guarantee safe data sharing amongst many stakeholders through case studies in smart manufacturing and healthcare.

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