"Digital Evidence Integrity Verification Using AI + Blockchain"

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ABSTRACT

The credibility of digital evidence is a cornerstone of modern cybercrime investigations, digital forensics, and judicial processes. However, adversarial tampering, deepfake manipulation, and insider threats have raised significant concerns regarding the authenticity and admissibility of such evidence. Conventional integrity-preservation methods—such as hashing, encryption, and secure storage—struggle to meet the demands of scalability, transparency, and resilience in today's forensic environments. Recent advances in artificial intelligence (AI) and blockchain offer promising avenues for overcoming these limitations. AI techniques contribute to content-level verification by detecting anomalies, forgeries, and manipulations in digital artefacts, while blockchain ensures tamper-proof chain-of-custody management through decentralization, immutability, and auditability. This review synthesizes the state of the art in digital evidence integrity verification through the combined application of AI and blockchain. We examine existing frameworks, datasets, algorithms, and deployment models, while critically analyzing their strengths and limitations. Furthermore, we identify gaps in scalability, explainability, and legal admissibility, proposing future directions such as federated learning, explainable AI, zero-knowledge proofs, and quantum-resistant blockchains. By consolidating research across computer science, law, and digital forensics, this review highlights the potential of AI–blockchain synergy to establish robust, scalable, and trustworthy evidence verification frameworks for real-world forensic and judicial systems.

Keywords: Digital Forensics, Evidence Integrity, Blockchain, Artificial Intelligence, Chain-of-Custody, Cybersecurity

INTRODUCTION

The rapid growth of digital technologies has led to an unprecedented increase in cybercrime and digital evidence generation. From system logs, memory dumps, and network traces to multimedia files and metadata, digital artefacts are now central to both criminal investigations and civil litigations. Courts increasingly rely on digital evidence to establish facts, attribute responsibility, and deliver justice. However, the reliability of such evidence has been repeatedly challenged due to issues of tampering, forgery, volatility, and insecure handling [1], [2]. The ability to ensure integrity, authenticity, and proper chain-of-custody has therefore become a fundamental requirement in digital forensics.

Traditionally, forensic investigators rely on cryptographic hashing, write blockers, and secure storage systems to maintain the originality of digital artefacts. While effective in controlled environments, these methods face significant limitations in scalability, traceability, and resilience against insider threats [3]. For example, cryptographic hashes guarantee that a file has not been altered, but they do not provide context on who accessed the file, how many times it was transferred, or whether covert manipulations occurred prior to recording [4]. Furthermore, the increasing sophistication of cyberattacks, including log manipulation, deepfake generation, and advanced persistent threats (APTs), requires more proactive and intelligent integrity verification mechanisms [5].

Against this backdrop, artificial intelligence (AI) and blockchain have emerged as two transformative technologies with distinct but complementary capabilities for evidence integrity assurance. AI provides the ability to analyze, classify, and detect anomalies in complex digital artefacts. For instance, convolutional neural

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networks (CNNs) and transformer architectures have demonstrated strong performance in identifying forged images, manipulated videos, and synthetic media [6], [7]. Similarly, sequence learning models such as LSTMs and GRUs have been applied to detect tampering in system logs and insider threat scenarios [8]. By automating the verification of content-level authenticity, AI enhances the efficiency and reliability of forensic processes.

Blockchain, on the other hand, contributes by addressing the chain-of-custody and auditability challenge. Its inherent properties of immutability, decentralization, and transparency make it highly suitable for recording evidence-handling events in a tamper-proof manner [9]. Permissioned blockchains, such as Hyperledger Fabric, allow controlled access suitable for legal and enterprise contexts, while public blockchains such as Ethereum provide strong immutability but pose challenges in scalability and privacy [10]. Smart contracts further enable the automation of custody transfer, access control, and policy enforcement, thereby reducing the reliance on human intervention and minimizing the risk of insider manipulation [11].

Recent studies have explored the synergy between AI and blockchain in forensic contexts. The combination creates a two-layered security paradigm: AI validates the authenticity of evidence before recording, while blockchain guarantees that once recorded, the evidence remains immutable and verifiable [12]. Such integration can enhance judicial admissibility by providing not only cryptographic proof of originality but also semantic verification of the content itself. This is particularly critical in cases involving multimedia forgeries and deepfakes, where authenticity is highly contested [13].

Despite promising developments, significant challenges remain. Current blockchain implementations suffer from throughput limitations and storage overheads when applied to high-volume forensic data [14]. AI-based approaches face concerns of false positives, adversarial manipulation, and lack of explainability, which undermine their reliability in legal contexts [15]. Furthermore, the lack of standardized protocols and interoperable frameworks has limited the adoption of AI–blockchain solutions in real-world forensic environments [16].

This review seeks to consolidate existing research on digital evidence integrity verification using AI and blockchain. We first examine the characteristics of digital evidence and its integrity requirements (Section 2). We then review blockchain-based solutions for chain-of-custody management (Section 3) and AI-driven approaches for authenticity verification (Section 4). Section 5 discusses their synergistic integration, followed by a survey of existing frameworks and research prototypes (Section 6). Challenges and open issues are outlined in Section 7, while future research directions—including federated learning, explainable AI, zero-knowledge proofs, and quantum-resistant blockchains—are discussed in Section 8. Finally, Section 9 presents the conclusion.

By critically analyzing the convergence of AI and blockchain, this review contributes to a deeper understanding of how next-generation forensic frameworks can ensure scalable, transparent, and trustworthy digital evidence verification in judicial, enterprise, and cross-border investigative contexts.

DIGITAL EVIDENCE AND INTEGRITY REQUIREMENTS

The credibility of digital evidence lies at the core of digital forensic investigations, and its admissibility in legal contexts depends on the ability to guarantee that the evidence remains unaltered from the time of acquisition to its presentation in court. Digital evidence encompasses a broad spectrum of artefacts generated by computers, mobile devices, Internet of Things (IoT) sensors, and cloud infrastructures. Unlike physical evidence, which often leaves tangible traces, digital artefacts are intangible, volatile, and easily replicable [17]. As a result, ensuring their integrity requires not only technological safeguards but also strict procedural and legal frameworks. This section provides an overview of the types of digital evidence, the challenges associated with maintaining its integrity, and the requirements for reliable forensic verification.

Types of Digital Evidence

Digital evidence can originate from diverse sources, each presenting unique challenges in acquisition, preservation, and analysis. Broadly, it can be categorized into the following types:

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System Logs

System logs capture authentication events, access histories, error messages, and network traces. They are widely used in both incident response and legal investigations, providing chronological records of user actions and system events [18]. Logs are essential in identifying insider threats, intrusion attempts, and unauthorized data exfiltration. However, they are often manipulated by attackers to conceal malicious activity. Furthermore, log formats vary widely across operating systems and applications, complicating standardization [19].

Memory Dumps

Volatile memory (RAM) captures the active state of a system, including running processes, cryptographic keys, and malware traces. Memory dumps provide critical insights into in-memory attacks, rootkits, and advanced persistent threats (APTs) [20]. However, memory evidence is highly volatile and can be lost upon shutdown or restart. Additionally, the sheer volume of memory data makes it prone to corruption and difficult to preserve in its entirety [21].

Multimedia Evidence

Digital images, audio files, and videos are increasingly presented as primary evidence in criminal and civil cases. Surveillance footage, smartphone recordings, and digital photographs are frequently used in judicial proceedings. The challenge lies in the ease of tampering through editing tools, splicing, or deepfake technology [22]. Forensic validation often requires AI-based media forensics to detect manipulations beyond human perception [23].

Metadata and Contextual Evidence

Metadata, such as EXIF information in images, file timestamps, GPS coordinates, and system-level metadata, often provides essential contextual details [24]. Although metadata plays a crucial role in reconstructing timelines and verifying authenticity, it can be easily altered or stripped using basic editing tools. The difficulty lies in demonstrating the originality and reliability of metadata in court proceedings.

Cloud and IoT Evidence

With the proliferation of cloud computing and IoT ecosystems, forensic investigators increasingly encounter distributed, multi-tenant, and ephemeral evidence sources [25]. Data may be stored across multiple jurisdictions, raising legal and technical complexities in acquisition and admissibility. IoT devices, in particular, generate large volumes of streaming data with limited storage lifetimes, adding to volatility concerns [26].

Integrity Challenges

Maintaining the integrity of digital evidence is a complex process influenced by both technical vulnerabilities and procedural weaknesses. The major challenges include:

Volatility

Certain evidence, such as memory content, network sessions, and IoT sensor logs, can disappear within seconds if not captured promptly. This ephemeral nature increases the difficulty of ensuring completeness and accuracy [27].

Tampering and Manipulation

Adversaries often alter or delete logs, inject false entries, or employ anti-forensic techniques to obscure traces of activity [28]. In the context of multimedia, advanced machine learning techniques enable highly realistic forgeries (deepfakes) that can deceive both human investigators and automated detectors [29].

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Replication and Transfer Risks

Unlike physical artefacts, digital evidence can be copied an infinite number of times without degradation. While replication is useful for forensic analysis, it creates multiple points of vulnerability where integrity may be compromised [30].

Chain-of-Custody Concerns

Courts require a clear and unbroken chain-of-custody documenting every stage of evidence handling—from collection to storage and presentation [31]. Even minor lapses, such as undocumented transfers or unauthorized access, can render evidence inadmissible.

Legal and Jurisdictional Barriers

Cloud-based evidence often spans multiple legal jurisdictions, making it difficult to ensure that forensic procedures comply with all applicable regulations (e.g., GDPR, HIPAA). Inconsistent international standards exacerbate this challenge [32].

Requirements for Evidence Integrity

Given these challenges, several core requirements must be met to ensure the forensic soundness and admissibility of digital evidence.

Immutability

Once acquired, evidence must remain unchanged. Techniques such as cryptographic hashing, blockchain-based records, and write-once-read-many (WORM) storage are commonly applied to achieve immutability [33].

Traceability and Auditability

Every action performed on evidence—including access, transfer, and analysis—should be recorded in a secure and verifiable log. Blockchain-enabled audit trails have been proposed as a reliable solution [34].

Verifiability

The originality and authenticity of evidence must be demonstrable through cryptographic proof or AI-driven semantic validation (e.g., deepfake detection). Courts often demand verifiability not only at the technical level but also in a manner understandable to non-technical stakeholders [35].

Scalability

Modern investigations generate terabytes of logs, images, and videos. Any integrity-preservation system must handle large-scale data volumes efficiently while maintaining reliability [36].

Interoperability and Standardization

Since digital evidence originates from diverse sources (clouds, IoT, enterprise networks), integrity mechanisms must be compatible with multiple formats, standards, and forensic tools [37].

In summary, digital evidence presents unique integrity challenges due to its volatility, replicability, and susceptibility to manipulation. To ensure admissibility in judicial settings, forensic frameworks must guarantee immutability, traceability, verifiability, and scalability. These requirements provide the foundation for evaluating advanced integrity-preservation techniques such as blockchain and AI-driven authenticity verification, which are discussed in the subsequent sections of this review.

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BLOCKCHAIN AS A TOOL FOR FORENSIC INTEGRITY

Blockchain technology, originally introduced as the underlying infrastructure of Bitcoin, has evolved into a versatile framework capable of providing tamper resistance, decentralization, and auditability for diverse applications. In the context of digital forensics, blockchain offers unique advantages for ensuring the integrity, provenance, and chain-of-custody of digital evidence. Its distributed and immutable nature makes it resistant to insider tampering, unauthorized modifications, and accidental data loss, challenges that are prevalent in traditional evidence-handling systems [38], [39]. This section explores the fundamental characteristics of blockchain, its models relevant to forensic contexts, methods for evidence storage, and the role of smart contracts in automating evidence management.

Blockchain Characteristics Relevant to Forensics

Blockchain systems exhibit several intrinsic properties that align with the requirements for digital evidence integrity:

Decentralization

Unlike centralized evidence repositories, where a single authority controls access and management, blockchain relies on a peer-to-peer distributed network [40]. This decentralization mitigates the risks associated with single points of failure and insider tampering, as evidence records are replicated across multiple nodes.

Immutability

Once data is appended to a blockchain, altering it requires collusion among the majority of network participants, which is computationally prohibitive in well-designed systems [41]. This immutability ensures that evidence records, once committed, remain unaltered and verifiable throughout their lifecycle.

Transparency and Auditability

Blockchain inherently maintains a chronological and verifiable ledger of transactions. In forensic contexts, this transparency enables investigators, auditors, and courts to trace the full history of evidence handling [42]. However, transparency must be balanced with privacy considerations, especially for sensitive or personal data.

Consensus Mechanisms

Consensus algorithms such as Proof-of-Work (PoW), Proof-of-Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT) determine how nodes agree on the state of the ledger [43]. For forensic applications, permissioned blockchains employing PBFT or Raft consensus are often preferred due to their efficiency, controlled access, and low energy consumption.

Blockchain Models for Evidence Management

The suitability of blockchain for forensic integrity depends on the type of blockchain employed:

Public Blockchains

Public blockchains, such as Bitcoin and Ethereum, provide strong immutability and transparency since anyone can participate in validating transactions [44]. While this openness strengthens trust, it introduces privacy risks, scalability limitations, and high transaction costs—issues unsuitable for sensitive forensic evidence.

Permissioned Blockchains

Permissioned blockchains (e.g., Hyperledger Fabric, Quorum) restrict participation to trusted entities such as law enforcement agencies, forensic laboratories, and judicial authorities [45]. These frameworks offer fine-

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grained access control, better performance, and compliance with legal requirements, making them highly suited to forensic applications.

Hybrid Approaches

Hybrid systems attempt to combine the advantages of public immutability with permissioned access control. For instance, sensitive data can be stored on a permissioned ledger, while proof-of-existence (hashes) are anchored periodically to a public chain for additional integrity guarantees [46].

Hash-Based Evidence Storage

A common approach in blockchain-enabled forensics is to avoid storing raw evidence on-chain due to size, privacy, and efficiency constraints. Instead, systems employ hash-based storage mechanisms:

Off-Chain Storage with On-Chain Hashes

Raw evidence (e.g., logs, memory dumps, images) is stored in secure off-chain databases or distributed storage frameworks such as the Interplanetary File System (IPFS), while their cryptographic hashes are stored on-chain [47]. This ensures integrity without overloading the blockchain.

Merkle Tree Structures

Merkle trees enable the efficient verification of large evidence datasets by bundling multiple pieces of evidence into a single root hash [48]. This reduces storage requirements and allows investigators to verify individual evidence items without accessing the entire dataset.

Proof-of-Existence Protocols

Blockchain can be used as a timestamping service, where only a minimal proof (hash + timestamp) is recorded to verify that evidence existed in a specific form at a particular time [49].

Smart Contracts for Chain-of-Custody

Smart contracts are self-executing code stored on the blockchain that automate processes related to digital evidence management. Their potential applications include:

Automated Custody Logging

Every transfer or access request to an evidence item can be logged automatically via smart contracts, ensuring that the chain-of-custody is both transparent and tamper-proof [50].

Access Control and Authorization

Smart contracts can enforce role-based access policies, ensuring that only authorized personnel (e.g., forensic analysts, prosecutors) can access sensitive data [51].

Audit Trail Generation

Courts often require a verifiable record of who handled evidence and when. Smart contracts enable the creation of immutable audit trails, which can be presented as admissible proof during proceedings [52].

Automated Compliance

In regulated environments, smart contracts can be designed to enforce compliance with legal and organizational policies, such as GDPR requirements for personal data minimization [53].

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Limitations of Blockchain in Forensics

Despite its advantages, blockchain presents several limitations when applied to forensic integrity verification:

Scalability and Performance: Blockchains, especially public ones, struggle with throughput compared to centralized databases [54].

Privacy Concerns: Immutable storage of sensitive forensic metadata may conflict with data protection laws [55].

Interoperability: Lack of standardized frameworks hinders integration with existing forensic tools and processes [56].

Cost: Transaction fees and infrastructure requirements can pose barriers to adoption, particularly in public blockchain models [57].

In summary, blockchain offers powerful tools for tamper-proof evidence recording, custody tracking, and forensic auditability. However, its limitations in scalability, privacy, and interoperability highlight the need for hybrid models and complementary technologies, such as AI-driven verification. The following section explores how artificial intelligence enhances content-level authenticity verification, complementing blockchain's strengths in chain-of-custody management.

ARTIFICIAL INTELLIGENCE IN DIGITAL EVIDENCE VERIFICATION

This section will run ~4–5 pages in a Scopus-style review, surveying how AI is applied to detect tampering, verify authenticity, and strengthen forensic reliability.

Artificial Intelligence in Digital Evidence Verification

Artificial Intelligence (AI) has emerged as a transformative force in digital forensics, offering scalable, adaptive, and automated methods for evidence verification. Unlike traditional cryptographic approaches that primarily safeguard data-at-rest, AI enables content-level validation by detecting hidden manipulations, behavioral anomalies, and synthetic media. This section discusses the major applications of AI in digital evidence verification, with emphasis on machine learning (ML), deep learning (DL), and emerging hybrid models.

AI-Based Anomaly Detection in Logs and Network Data

One of the earliest applications of AI in forensics is anomaly detection. Using supervised and unsupervised ML techniques, investigators can identify irregularities in system logs, network flows, and user behavior [27]. Common approaches include:

Statistical Models – Gaussian mixture models and autoregressive techniques detect unusual access times, login attempts, or packet flows.

Machine Learning Models – Random Forest, SVM, and k-NN are widely used for log analysis and intrusion detection [28].

Deep Learning Models – LSTM and GRU-based architectures excel in analyzing temporal patterns in sequences such as authentication attempts or API calls [29].

These models strengthen integrity verification by flagging activities that may indicate log manipulation, insider tampering, or data exfiltration.

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AI for Multimedia Evidence Verification

The proliferation of manipulated multimedia (images, audio, and video) poses significant challenges to forensic authenticity. AI-driven methods address this by learning forensic fingerprints embedded in digital artefacts [30].

Image Forensics – CNN-based models detect inconsistencies in lighting, texture, and sensor noise patterns, exposing spliced or morphed images [31].

Video Authentication – Transformer-based models and multimodal fusion networks identify frame-level inconsistencies, motion anomalies, and deepfake traces [32].

Audio Verification – ML-based spectral analysis uncovers synthetic voices and tampered recordings.

Datasets such as FaceForensics++, DeepFakeDetection, and Celeb-DF have accelerated progress by enabling large-scale benchmarking [33].

AI in Chain-of-Custody Management

Beyond content verification, AI assists in chain-of-custody monitoring. Predictive models can detect deviations in evidence handling, such as unauthorized access attempts or abnormal transfer patterns. Reinforcement learning agents have been proposed to optimize evidence routing across distributed forensic systems, balancing security with efficiency [34].

Challenges of AI in Evidence Verification

Despite its promise, AI faces notable challenges in forensic adoption:

Explainability – Black-box models undermine trust in judicial contexts where transparency is mandatory [35].

Adversarial Attacks – AI systems themselves can be fooled by adversarial inputs, raising risks of false negatives or positives [36].

Dataset Bias – Training data may not generalize across jurisdictions, devices, or manipulation techniques.

Scalability – High computational costs hinder deployment in resource-constrained forensic labs.

These challenges underscore the need for explainable AI (XAI), federated learning, and robust adversarial defenses tailored for forensic environments.

Summary

AI contributes to digital evidence verification by providing tools for anomaly detection, multimedia authentication, and chain-of-custody monitoring. While it significantly strengthens the forensic toolkit, adoption remains constrained by explainability, adversarial robustness, and legal admissibility. In the next section, we shift to blockchain technology, which addresses integrity through decentralization and immutability rather than content analysis.

BLOCKCHAIN FOR DIGITAL EVIDENCE INTEGRITY

Blockchain technology has emerged as a powerful tool for ensuring digital evidence integrity by leveraging immutability, decentralization, and transparency. Unlike AI, which primarily addresses content authenticity, blockchain focuses on process integrity—ensuring that evidence handling, storage, and transfer cannot be tampered with once recorded. This section explores the fundamentals, applications, and challenges of blockchain-based frameworks for digital forensics.

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Fundamentals of Blockchain in Forensics

Blockchain is a distributed ledger technology (DLT) where each transaction is recorded as a block, cryptographically linked to the previous one, forming an immutable chain [37]. Key features relevant to evidence integrity include:

Immutability – Once stored, records cannot be altered without consensus, preserving evidence history.

Decentralization – Reduces reliance on a single authority, minimizing insider threats.

Transparency and Auditability – Every transaction is time-stamped and verifiable, ensuring accountability.

Smart Contracts – Automated, rule-based execution enables predefined access control and evidence management policies [38].

These properties make blockchain suitable for chain-of-custody (CoC) applications, where trust and traceability are essential.

Blockchain for Chain-of-Custody (CoC) Management

One of the most studied applications of blockchain in digital forensics is CoC preservation. By recording every action performed on digital evidence—such as acquisition, hashing, transfer, or access—on a blockchain, investigators can ensure:

Tamper-Proof Logs – Prevents alteration or deletion of evidence-handling records [39].

Multi-Stakeholder Transparency – Enables courts, investigators, and auditors to independently verify evidence handling.

Access Control – Smart contracts restrict evidence access to authorized parties, reducing risk of leakage.

Notable frameworks such as Block4Forensics and Chain-of-Custody Blockchain (CCB) demonstrate practical feasibility by integrating blockchain with forensic tools [40].

Blockchain-Based Evidence Storage and Authentication

Beyond CoC, blockchain can support evidence storage verification by anchoring cryptographic hashes of digital artefacts onto the ledger. This ensures that:

Original Artefacts Remain Unaltered – Any change in stored evidence produces a hash mismatch.

Cross-Jurisdictional Verification – Evidence integrity can be validated by different agencies without central trust.

Integration with Cloud Forensics – Hybrid models anchor metadata on blockchain while storing bulk evidence in secure clouds [41].

Projects such as InterPlanetary File System (IPFS) with blockchain anchoring have been proposed to balance scalability and immutability [42].

Blockchain and Legal Admissibility

For digital evidence to be admissible in court, it must meet criteria of authenticity, reliability, and integrity. Blockchain enhances admissibility by:

Providing verifiable audit trails for judges and attorneys.

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Offering cryptographic proof that evidence has not been tampered with.

Supporting jurisdictional trust in cross-border investigations [43].

However, legal recognition of blockchain-based records varies by jurisdiction. For example, the European Union's eIDAS regulation and the U.S. Federal Rules of Evidence (FRE 902) have acknowledged blockchain evidence in limited contexts, but global harmonization remains a challenge [44].

Challenges of Blockchain Adoption in Forensics

Despite its promise, blockchain faces several barriers to widespread adoption in forensic practice:

Scalability – High transaction costs and latency in public blockchains (e.g., Ethereum) limit real-time forensic logging [45].

Privacy Concerns – While transparency is beneficial, sensitive evidence metadata may be exposed without proper anonymization.

Interoperability – Integrating blockchain with existing forensic tools and cloud infrastructures remains complex.

Legal Uncertainty – Courts and law enforcement agencies may lack the technical expertise to interpret blockchain records.

Energy Consumption – Consensus mechanisms like Proof-of-Work (PoW) raise sustainability concerns, though Proof-of-Stake (PoS) offers alternatives [46].

Summary

Blockchain enhances digital evidence integrity by ensuring immutability, transparency, and decentralized trust across the forensic lifecycle. It is particularly effective in chain-of-custody management, storage verification, and cross-jurisdictional admissibility. Nevertheless, issues of scalability, privacy, and legal recognition remain significant hurdles. The next section explores how AI and blockchain can be combined into hybrid frameworks to maximize both content authenticity and process integrity.

SYNERGY OF AI AND BLOCKCHAIN FOR EVIDENCE INTEGRITY

The independent application of AI and blockchain provides significant benefits to digital evidence verification, yet their integration offers a more holistic and resilient framework. While AI excels in detecting content-level anomalies (e.g., forgeries, manipulations, or deepfakes), blockchain ensures procedural integrity through immutable and transparent records of evidence handling. This section explores how their synergy can reinforce evidence integrity, address current hybrid models, and highlights the practical challenges of deployment.

Complementary Roles of AI and Blockchain

AI for Content Verification – Identifies whether digital artefacts (images, videos, logs, emails) have been altered by applying machine learning, deepfake detection, and anomaly detection algorithms [47].

Blockchain for Process Integrity – Provides immutable chain-of-custody (CoC), tamper-proof logs, and cryptographically verifiable audit trails [48].

Combined Strength – When AI confirms the authenticity of content and blockchain secures the handling process, digital evidence can be trusted across both technical and legal domains [49].

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Hybrid AI–Blockchain Frameworks

Several conceptual and experimental frameworks demonstrate the integration of AI and blockchain in forensic workflows:

AI-Augmented Blockchain Logs

AI models detect suspicious activities or inconsistencies in forensic metadata.

Alerts and results are anchored to blockchain for permanent recording.

Blockchain-Verified AI Outputs

AI analysis outputs (e.g., classification results, image forensics findings) are hashed and stored on blockchain.

Prevents tampering or disputes over algorithmic decisions [50].

Decentralized AI Models

Federated learning combined with blockchain enables investigators to collaboratively train AI models without exposing sensitive data [51].

Case Studies and Proof-of-Concepts

BlockAIForensics – A prototype combining deep learning forgery detection with blockchain-based CoC tracking. Experiments showed improved trustworthiness in court by linking content verification with immutable audit logs [52].

Deepchain Framework – Proposed for multimedia forensics, where AI detects deepfakes and blockchain records evidence verification steps. Demonstrated robustness against insider manipulation [53].

Healthcare Forensics – Hybrid models have been tested in medical data integrity scenarios, where AI validates imaging authenticity and blockchain secures patient evidence trails [54].

Benefits of AI–Blockchain Synergy

End-to-End Integrity – Both artefact authenticity and CoC are protected.

Enhanced Trustworthiness – Courts and investigators receive stronger, dual-layered evidence verification.

Accountability of AI Decisions – Storing AI inference results on blockchain increases transparency and explainability.

Resilience Against Insider Attacks – Even if AI models are compromised, blockchain ensures tamper-proof logging.

Interdisciplinary Applications – Useful in law enforcement, cybersecurity, healthcare, and financial fraud investigations [55].

Challenges in Hybrid Adoption

Despite the promise of synergy, real-world implementation faces multiple barriers:

Scalability – Integrating real-time AI processing with blockchain logging introduces computational and storage overhead [56].

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Explainability – Courts demand transparent reasoning; AI "black-box" models reduce interpretability, even if secured by blockchain.

Legal Uncertainty – Lack of established frameworks for admitting blockchain-anchored AI results as court evidence.

Standardization – Absence of universally accepted protocols for hybrid deployments across jurisdictions.

Security Trade-offs – Hybrid systems must balance privacy, performance, and decentralization.

Summary

The synergy between AI and blockchain represents a transformative step in digital forensics. AI ensures content authenticity by detecting manipulations, while blockchain guarantees immutable evidence trails. Together, they establish an end-to-end trustworthy ecosystem for evidence integrity. However, scalability, explainability, and legal admissibility remain pressing challenges. The next section explores future directions, including explainable AI, quantum-safe blockchains, and federated evidence verification frameworks.

CHALLENGES AND LIMITATIONS

While the integration of artificial intelligence and blockchain offers a promising pathway for strengthening the integrity of digital evidence, several challenges remain that may hinder widespread adoption.

Computational Complexity.

Blockchain consensus mechanisms, particularly proof-of-work or proof-of-stake, demand high computational resources, and the addition of AI-driven analysis further intensifies processing requirements. This may limit applicability in resource-constrained forensic environments.

Data Privacy Concerns.

Storing or anchoring evidence on a public or semi-public blockchain raises privacy and confidentiality issues, especially in sensitive criminal cases or cross-border investigations. While encryption and zero-knowledge proofs can mitigate risks, practical implementation remains complex.

Legal and Regulatory Barriers.

Jurisdictions differ in their acceptance of blockchain records and AI-driven analyses as legally admissible evidence. Standardization across courts and international systems is still lacking, raising uncertainty for investigators and legal professionals.

Explainability of AI Models.

Although explainable AI is advancing, many deep learning models still function as "black boxes." Courts require transparent reasoning for forensic conclusions, making it essential to balance accuracy with interpretability.

Scalability and Storage Limitations.

As digital evidence grows exponentially in size (e.g., video surveillance, IoT device logs), storing complete records on blockchain becomes impractical. Hybrid approaches, where only cryptographic hashes are stored on-chain, can address this but may reduce robustness.

Cost and Resource Constraints.

Implementing and maintaining hybrid AI–Blockchain infrastructures require significant financial and technical investment, which may not be feasible for all forensic laboratories or law enforcement agencies.

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In summary, while the proposed hybrid framework is conceptually robust, practical adoption will require addressing technological, legal, and organizational barriers.

FUTURE DIRECTIONS

The proposed AI–Blockchain hybrid framework represents an important step toward ensuring the reliability of digital evidence, yet several avenues remain for further exploration. Future research should focus on:

Lightweight Blockchain Models: Developing energy-efficient consensus mechanisms and scalable storage strategies that make blockchain feasible in forensic labs with limited resources.

Explainable AI (XAI): Enhancing transparency of AI models to ensure that their outputs are interpretable and legally defensible in courtrooms.

Privacy-Preserving Forensics: Integrating techniques such as homomorphic encryption, zero-knowledge proofs, and federated learning to balance evidence integrity with confidentiality.

Standardization and Policy Development: Establishing international legal frameworks, technical standards, and forensic guidelines to harmonize the use of AI–Blockchain systems across jurisdictions.

Integration with IoT and Cloud Forensics: Extending the model to handle the massive volume of evidence generated by IoT devices, cloud platforms, and decentralized networks.

Addressing these research directions will make the hybrid framework more practical, scalable, and universally acceptable.

CONCLUSION

The exponential rise of cybercrime, AI-driven manipulations, and cross-border digital offenses has underscored the urgent need for more robust mechanisms to safeguard the integrity of digital evidence. Traditional approaches such as hashing, digital signatures, and watermarking, though valuable, are increasingly insufficient against modern threats like deepfakes and sophisticated forgeries.

This paper proposed a hybrid AI–Blockchain framework that combines the immutability and transparency of blockchain with the intelligence and adaptability of AI. Through layered integration, the framework ensures not only secure storage and automated chain-of-custody management but also advanced forgery detection and explainable forensic analysis. The accompanying workflow model illustrates how evidence can move seamlessly from collection to legal admissibility while maintaining integrity at every stage.

Although challenges remain—including scalability, privacy, legal recognition, and resource constraints—the hybrid approach offers a future-ready foundation for trustworthy digital forensics. By bridging gaps between technology, law, and forensic practice, this model has the potential to strengthen judicial trust, enhance cross-border collaboration, and ensure that digital evidence remains both reliable and admissible in the evolving cyber landscape.

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