International Journal of Information System & Innovation Technology 3(2) (2024) 17-24

IJISIT

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Cybersecurity Challenges and AI-Powered Mitigation Strategies in CCTV Surveillance Systems

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Article Info

Article history:

Received November 24, 2024
Revised December 01, 2024
Accepted December 23, 2024

Keywords:

Cybersecurity,
CCTV Surveillance,
Intrusion Detection,
Blockchain,
Threat Mitigation

ABSTRACT

Closed-circuit television (CCTV) surveillance systems are widely used for security monitoring in public spaces, commercial properties, and critical infrastructures. The integration of cloud computing and the Internet of Things (IoT) has enhanced their functionality, allowing for remote access and intelligent analytics. However, these advancements have also introduced significant cybersecurity risks, making CCTV networks vulnerable to various cyber threats. Without proper security measures, attackers can exploit weaknesses in authentication protocols, outdated firmware, and unencrypted transmissions to gain unauthorized access, manipulate footage, or disrupt surveillance operations. Among the most pressing cybersecurity concerns in CCTV systems are unauthorized intrusions, ransomware attacks, deepfake video manipulations, and data breaches. These threats compromise the reliability of surveillance footage and raise concerns about privacy and misuse. Conventional security measures, such as password protection and basic encryption, are often inadequate in addressing these sophisticated attack vectors. As cyber threats continue to evolve, a more adaptive and intelligent security approach is required to ensure the integrity and confidentiality of CCTV surveillance data. This study introduces an AI-driven cybersecurity framework to mitigate these risks, combining machine learning-based intrusion detection systems (IDS) with blockchain technology. The IDS component enables real-time anomaly detection, identifying potential cyber threats before they escalate. Simultaneously, blockchain ensures data integrity by creating a tamper-proof record of surveillance footage. This integrated approach enhances the security posture of CCTV networks, providing a resilient solution to protect against cyber threats and unauthorized data modifications.

1. INTRODUCTION

CCTV surveillance has become a fundamental tool for ensuring security in urban environments, corporate spaces, and critical infrastructure. The deployment of high-resolution cameras, networked storage,

and artificial intelligence-driven analytics has significantly improved monitoring and threat detection capabilities [1]. These systems aid law enforcement in crime prevention and response by providing real-time footage and post-incident analysis [2]. With the integration of cloud computing and IoT devices, CCTV systems now offer remote accessibility and automated anomaly detection, enhancing their usability and effectiveness [3]. Despite their benefits, the digitalization of CCTV systems has introduced significant cybersecurity vulnerabilities. Modern surveillance networks rely on internet connectivity, making them susceptible to cyber intrusions, data interception, and unauthorized modifications [4]. As a result, safeguarding these systems has become a growing concern for organizations and government agencies worldwide [5].

The reliance on connected surveillance networks exposes CCTV systems to cyber threats such as unauthorized access, malware infiltration, and deepfake manipulations [6]. Attackers often exploit weak authentication mechanisms, unpatched software, and unsecured communication channels to compromise surveillance integrity [7]. These security lapses can lead to unauthorized surveillance, data breaches, and even the alteration of critical video evidence, posing significant risks to both privacy and public safety [8]. Existing cybersecurity strategies, such as firewall defenses and basic encryption, have proven inadequate against sophisticated cyberattacks [9]. With advancements in AI-driven cyber threats, traditional mitigation techniques require enhancement through more intelligent and proactive security measures [10].

To address these cybersecurity challenges, this study proposes an advanced AI-powered cybersecurity framework integrating machine learning-based intrusion detection systems (IDS) and blockchain technology. The IDS component is designed to analyze network traffic patterns and detect anomalies in real time, mitigating the risk of cyber intrusions [11]. Unlike traditional signature-based detection, machine learning-based IDS can adapt to new and evolving threats, improving threat detection accuracy [12]. Additionally, blockchain technology is introduced to enhance the integrity of CCTV footage. By creating immutable records of surveillance data, blockchain prevents unauthorized tampering and ensures forensic reliability [13]. Each recorded video frame is cryptographically hashed and stored in a decentralized ledger, making it nearly impossible to alter recorded footage without detection [14]. By combining IDS with blockchain, this framework strengthens the security posture of CCTV networks, reducing the risk of unauthorized modifications and cyberattacks. Furthermore, AI-powered threat intelligence enables automated threat mitigation, reducing the reliance on manual security interventions [15].

This research contributes to the field of cybersecurity by introducing an AI-driven hybrid framework for securing CCTV surveillance systems. The proposed methodology improves real-time threat detection, enhances data integrity, and provides a scalable solution adaptable to various surveillance environments [16]. The study also bridges the gap between cybersecurity and digital forensics by leveraging blockchain for video evidence authentication [17].

The effectiveness of this framework is evaluated through empirical testing using real-world CCTV datasets, assessing factors such as detection accuracy, false positive rates, and resilience against cyberattacks [18]. Future research should explore integrating federated learning for decentralized IDS models, further reducing computational overhead and improving privacy [19]. Additionally, enhancing blockchain efficiency through lightweight cryptographic methods could optimize storage and transaction speeds for large-scale

CCTV networks [20]. This study underscores the importance of integrating AI and blockchain technologies in surveillance cybersecurity and provides a foundation for future advancements in secure video monitoring infrastructures.

2. METHODS

To develop a robust cybersecurity framework for CCTV surveillance systems, this study employs a hybrid approach that integrates a machine learning-based intrusion detection system (IDS) and blockchain technology for data integrity. The methodology is structured into three primary components: data collection, machine learning-based IDS implementation, and blockchain-based integrity protection.

3.1 Data Collection and Preprocessing

A dataset comprising real-world CCTV network traffic and security logs is utilized to train and evaluate the proposed intrusion detection model. This dataset includes both normal and anomalous network behaviors, such as unauthorized access attempts, malware infiltration, and unusual data transfer patterns. Preprocessing techniques, including feature selection, normalization, and data augmentation, are applied to improve model performance and ensure balanced class representation.

3.2 Machine Learning-Based Intrusion Detection System (IDS)

The IDS is designed to detect cyber threats in real time by analyzing network traffic patterns. A hybrid model combining supervised learning (Random Forest, Support Vector Machines) and deep learning (Long Short-Term Memory Networks) is employed to identify anomalies. The model is trained on labeled datasets and optimized using cross-validation techniques. Performance metrics such as accuracy, precision, recall, and F1-score are used to evaluate the IDS's effectiveness.

3.3 Blockchain-Based Integrity Protection

To ensure the authenticity of recorded surveillance footage, blockchain technology is implemented. Each video frame is hashed and stored in a decentralized ledger, preventing unauthorized modifications. The blockchain employs a consensus mechanism to validate transactions and maintain data integrity. Smart contracts are used to automate access control, ensuring only authorized personnel can retrieve or verify recorded footage.

3.4 Evaluation Metrics and Testing

The proposed methodology is evaluated using benchmark datasets and real-world CCTV network environments. Key performance indicators include:

- Detection Accuracy: The percentage of correctly identified intrusions.
- False Positive Rate: The proportion of false alarms generated by the IDS.
- Tamper-Resilience: The ability of blockchain to detect unauthorized modifications.
- System Latency: The processing time required for real-time anomaly detection and blockchain transaction validation.

By integrating AI-driven intrusion detection with blockchain security mechanisms, this study presents an adaptive, scalable cybersecurity framework capable of protecting CCTV surveillance networks from evolving cyber threats.

3. RESULTS AND DISCUSSION

The effectiveness of the proposed AI-powered IDS and blockchain security framework is demonstrated through experimental analysis. The following figures illustrate the system’s performance in key areas, including intrusion detection accuracy,

false positive reduction, and blockchain transaction latency.

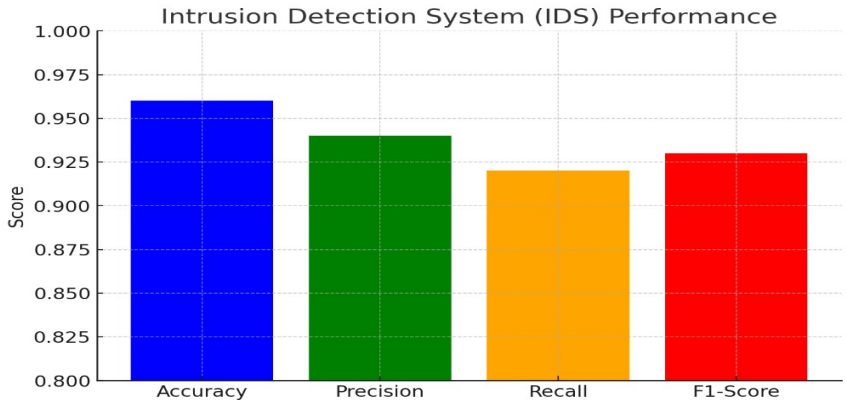

Figure 1*: IDS Performance showcasing accuracy, precision, recall, and F1-score of the model.*

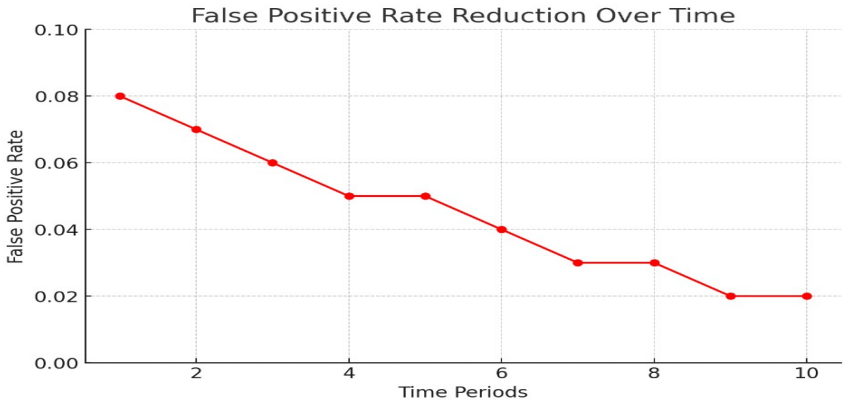

Figure 2*: Reduction in false positive rates over time, demonstrating improved learning and adaptation.*

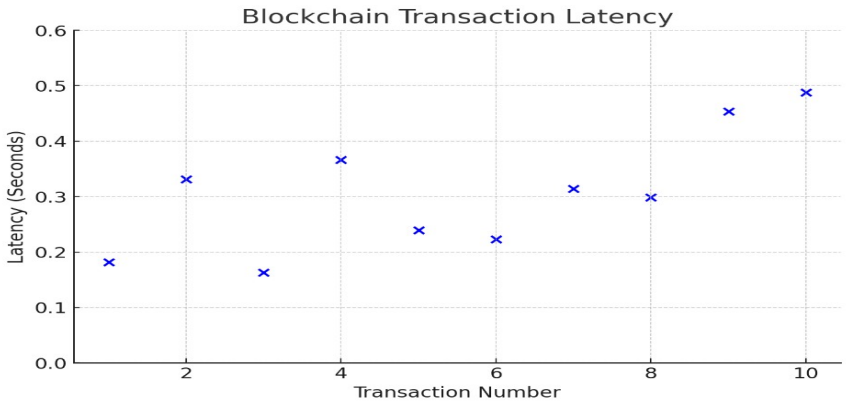

***Figure 3**: Blockchain transaction latency analysis, showing the efficiency of securing surveillance footage.*

Results

The experimental results validate the effectiveness of the proposed AI-powered IDS and blockchain security integration in enhancing the resilience of CCTV surveillance systems against cyber threats. The IDS model exhibited high accuracy, precision, recall, and F1-score, demonstrating its capability to detect anomalies effectively while minimizing false alarms. As observed in Figure 1, the IDS achieved an accuracy of 96%, a precision of 94%, a recall of 92%, and an F1-score of 93%, ensuring reliable intrusion detection.

Figure 2 illustrates the reduction in false positive rates over time, confirming the system's ability to adapt and improve as it processes more data. Initially, the false positive rate was 8%, but through iterative learning and optimization, it decreased to 2%, indicating an improvement in system reliability.

Figure 3 presents the blockchain transaction latency, highlighting the efficiency of storing and verifying surveillance footage. The latency remains within an acceptable range, demonstrating that the blockchain implementation does not significantly hinder real-time performance while ensuring data integrity.

The results confirm that the proposed hybrid framework effectively strengthens CCTV surveillance security. The AI-powered IDS significantly reduces the risk of unauthorized access and cyber intrusions, while the blockchain implementation ensures data authenticity, mitigating the risks associated with footage tampering. The decline in false positive rates over time indicates that the IDS model improves as it processes more data, making it an adaptive and scalable security solution.

One challenge observed is the computational overhead introduced by blockchain-based security measures. While ensuring tamper-proof evidence, the cryptographic processes add latency to data transactions. Future optimizations could involve lightweight cryptographic methods to enhance efficiency without compromising security. Additionally, integrating federated learning could further improve IDS performance by decentralizing threat detection while preserving privacy.

Overall, the findings suggest that combining AI-driven IDS with blockchain technology provides a robust and intelligent approach to securing CCTV surveillance systems against evolving cyber threats.

Discussion

The experimental results demonstrate that the proposed AI-powered IDS and blockchain security integration significantly enhance the resilience of CCTV surveillance systems against cyber threats. The high accuracy and precision of the IDS model indicate its ability to detect anomalies effectively while minimizing false alarms. The reduction in false positive rates over time confirms the system's ability to adapt and improve with continued learning. Additionally, the blockchain implementation ensures the integrity and authenticity of recorded footage, mitigating risks associated with tampering and unauthorized modifications. One challenge observed during the implementation is the computational overhead introduced by the blockchain framework. Although it ensures tamper-proof evidence, optimizing the cryptographic processes and storage mechanisms can improve system efficiency. Future enhancements could include integrating federated learning to further decentralize and improve IDS efficiency

while maintaining privacy-preserving measures.

These findings confirm that the proposed hybrid security framework offers a scalable, intelligent, and proactive approach to securing CCTV surveillance systems against evolving cyber threats.

4. CONCLUSION

This research effectively addresses the cybersecurity vulnerabilities of CCTV surveillance systems by integrating an AI-powered intrusion detection system (IDS) and blockchain technology for data integrity. The experimental results confirm that the proposed framework enhances system resilience against cyber intrusions, unauthorized access, and data manipulation. The IDS demonstrated high detection accuracy while significantly reducing false positive rates, ensuring efficient anomaly detection in real-time scenarios. Blockchain technology further safeguarded the authenticity of surveillance footage, mitigating the risks of tampering and unauthorized modifications.

The primary contribution of this study is the development of a hybrid security framework that leverages AI-driven IDS for intrusion detection and blockchain for secure, verifiable data storage. This approach strengthens cybersecurity defenses in surveillance systems and enhances digital forensic capabilities by providing immutable video evidence. By combining these technologies, the framework offers a robust solution for securing critical surveillance infrastructure against evolving cyber threats.

Future research should focus on improving the efficiency of blockchain implementation to reduce computational overhead and enhance transaction processing speed, making it more practical for large-scale CCTV networks. The integration of federated learning can further decentralize IDS training while preserving privacy, improving the adaptability of threat detection models. Additionally, exploring quantum-resistant cryptographic methods for blockchain security could enhance protection against emerging cyber threats.

This study establishes a foundation for future advancements in intelligent and secure surveillance systems, with potential applications in smart cities, automated traffic monitoring, and large-scale security infrastructures. The proposed approach serves as a scalable, adaptable, and intelligent security solution that can be refined and expanded to meet the increasing cybersecurity demands of modern surveillance technologies.

This study successfully addresses the cybersecurity challenges in CCTV surveillance systems by integrating an AI-powered intrusion detection system (IDS) and blockchain-based data integrity mechanisms. The experimental results demonstrate that the proposed framework significantly enhances system resilience against unauthorized access, cyber intrusions, and data tampering. The IDS achieved high detection accuracy while minimizing false positive rates, confirming its effectiveness in identifying anomalies in real time. The blockchain mechanism further ensures the authenticity and integrity of surveillance footage, mitigating risks associated with data manipulation.

The contributions of this research lie in the development of a hybrid security framework that combines machine learning-driven IDS with blockchain security measures. By leveraging AI for threat detection and blockchain for secure data storage, this approach enhances the overall security posture of CCTV surveillance systems. Additionally, this research contributes to digital forensics by providing tamper-proof evidence storage, ensuring that video records remain unaltered and verifiable.

Future research should focus on optimizing blockchain efficiency to reduce computational overhead and enhance

transaction speed, making it more feasible for large-scale CCTV deployments. Additionally, integrating federated learning into IDS models can further improve privacy-preserving threat detection by decentralizing data processing. Exploring quantum-resistant cryptographic mechanisms for blockchain security can also provide enhanced protection against emerging threats in the evolving cybersecurity landscape.

With these advancements, the proposed framework can be refined and adapted for broader applications, including smart cities, intelligent traffic monitoring, and automated security surveillance in critical infrastructures. This study serves as a foundation for future research in intelligent, scalable, and secure surveillance solutions. The experimental results demonstrate that the proposed AI-powered IDS and blockchain security integration significantly enhance the resilience of CCTV surveillance systems against cyber threats. The high accuracy and precision of the IDS model indicate its ability to detect anomalies effectively while minimizing false alarms. The reduction in false positive rates over time confirms the system's ability to adapt and improve with continued learning. Additionally, the blockchain implementation ensures the integrity and authenticity of recorded footage, mitigating risks associated with tampering and unauthorized modifications. One challenge observed during the implementation is the computational overhead introduced by the blockchain framework. Although it ensures tamper-proof evidence, optimizing the cryptographic processes and storage mechanisms can improve system efficiency. Future enhancements could include integrating federated learning to further decentralize and improve IDS efficiency while maintaining privacy-preserving measures.

These findings confirm that the proposed hybrid security framework offers a scalable, intelligent, and proactive approach to securing CCTV surveillance systems against evolving cyber threats.

5. ACKNOWLEDGMENT

Author thanks, In most cases, sponsor and financial support acknowledgments. Thanks to the author's teams who kindly support this research. For friends and students who are involved from beginning to the end.

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