CITE PUBLICATIONS

International Journal of Multidisciplinary Engineering Sciences

Volume: 1, Issue: 1, 2026 (January - June), Pages: 1-6

Review Article

Artificial Intelligence-Based Industrial IoT Security Framework using Machine Learning and Blockchain

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Received: 2 January 2026 / Accepted: 21 March 2026 / Published: 20 May 2026

Industrial Internet of Things (IIoT) technologies have transformed modern industrial environments by enabling intelligent automation, real-time monitoring, predictive maintenance, and smart manufacturing operations. However, the rapid adoption of interconnected industrial devices has introduced significant cybersecurity challenges including unauthorized access, ransomware attacks, data breaches, distributed denial-of-service attacks, and network intrusions. Traditional security mechanisms are insufficient to protect large-scale IIoT infrastructures due to device heterogeneity, limited computational capabilities, and dynamic industrial environments. This paper proposes an Artificial Intelligence-based Industrial IoT security framework integrating machine learning and blockchain technologies for secure industrial communication and intelligent threat detection. The proposed framework employs IoT sensors, edge computing, cloud infrastructure, and AI-driven intrusion detection models to identify malicious activities in industrial networks. Blockchain technology is incorporated to ensure secure data sharing, authentication, and tamper-resistant communication among IIoT devices. Experimental analysis demonstrates improved detection accuracy, reduced false-positive rates, enhanced network security, and efficient real-time monitoring compared with conventional IIoT security approaches. The proposed system offers a scalable and intelligent solution suitable for Industry 4.0 and smart manufacturing environments.

Keywords: *Industrial Internet of Things, Artificial Intelligence, Machine Learning, Blockchain, Cybersecurity, Intrusion Detection, Smart Manufacturing, Industry 4.0*

Introduction

The Industrial Internet of Things (IIoT) represents one of the most significant technological advancements in Industry 4.0 by enabling communication among industrial machines, sensors, controllers, and cloud platforms [1]. Modern industries increasingly depend on IIoT systems for automation, predictive maintenance, production monitoring, supply chain optimization, and intelligent decision-making [2]. The integration of connected devices with industrial infrastructures has improved operational efficiency, reduced downtime, and enhanced manufacturing productivity [3].
Despite these advantages, IIoT environments are highly vulnerable to cybersecurity threats because of increased connectivity and real-time data exchange [4]. Industrial control systems, smart sensors, programmable controllers, and edge devices continuously generate sensitive operational data, making them attractive targets for cyberattacks [5]. Common attacks in IIoT systems include malware injection, phishing, ransomware, denial-of-service attacks, insider threats, and unauthorized device access [6].

Traditional cybersecurity approaches are inadequate for modern IIoT systems due to device heterogeneity, limited hardware resources, and dynamic network structures [7]. Conventional encryption and firewall-based methods often fail to detect intelligent cyber threats and zero-day attacks [8]. Therefore, intelligent security mechanisms capable of adaptive threat detection and automated response are necessary for protecting industrial infrastructures. Artificial Intelligence (AI) and Machine Learning (ML) technologies have emerged as efficient solutions for cybersecurity applications in IIoT systems [9]. Machine learning algorithms can analyze industrial network traffic, identify anomalous

behavior, and detect malicious activities in real time [10]. Deep learning models further improve intrusion detection by recognizing complex attack patterns from large-scale industrial datasets [11]. Blockchain technology has also gained considerable attention in IIoT security because of its decentralized and tamper-resistant characteristics [12]. Blockchain ensures secure communication, device authentication, and transparent data management across distributed industrial environments [13]. Combining blockchain with AI-based intrusion detection mechanisms can significantly strengthen IIoT security architectures.

Recent industrial studies indicate that machine learning-enabled IIoT security systems can improve cyberattack detection accuracy and reduce operational risks in smart industries. This paper proposes an AI-based Industrial IoT security framework integrating machine learning and blockchain technologies for secure industrial communication and intelligent threat detection.

The major contributions of this research are,

1. Development of a secure AI-driven IIoT security architecture.
2. Integration of blockchain technology for secure industrial communication.
3. Implementation of machine learning algorithms for intrusion detection.
4. Real-time industrial threat monitoring using edge-cloud infrastructure.
5. Performance evaluation using industrial cybersecurity datasets.

1. Literature Survey

Several researchers have investigated security solutions for Industrial IoT systems using artificial intelligence and machine learning techniques. Alotaibi [14] presented a comprehensive survey on IIoT security requirements, attacks, AI-based solutions, and edge computing opportunities. The study emphasized the importance of intelligent threat detection mechanisms for industrial environments. Recent studies have shown that machine learning significantly enhances intrusion detection and anomaly analysis in IIoT environments. Kumar et al. [15] proposed a machine learning-enabled intrusion detection framework for industrial networks. Their model achieved high attack detection accuracy but faced scalability limitations in large industrial deployments. Rahman et al. [16] introduced a blockchain-based IIoT security architecture for protecting industrial communication channels. The proposed system improved data integrity and authentication mechanisms; however, blockchain overhead increased latency in real-time applications.

Federated learning and blockchain integration have recently gained attention for decentralized IIoT intrusion detection systems. Sharma and Gupta [17] developed an AI-assisted anomaly detection system using deep learning techniques for industrial automation systems. Their framework successfully detected malware attacks but required extensive computational resources. Chen et al. [18] proposed a blockchain-enabled authentication mechanism for Industry 4.0 environments. The study demonstrated improved device authentication and secure data transmission across industrial networks. Recent surveys emphasize that integrating AI, blockchain, and edge computing can improve security, scalability, and reliability in industrial IoT systems. Although existing research has contributed significantly to IIoT security, several limitations remain, including false-positive alerts, high processing overhead, scalability challenges, and limited real-time response capabilities. Therefore, an efficient AI-based IIoT security framework remains an important research requirement.

2. Proposed AI-Based Industrial IoT Security Framework

The proposed framework integrates IoT devices, blockchain networks, edge computing, and machine learning algorithms to provide intelligent industrial security management.

The architecture consists of five major layers,

1. Industrial Device Layer
2. Communication Layer
3. Edge Computing Layer
4. Blockchain Security Layer
5. AI-Based Threat Detection Layer

2.1 Industrial Device Layer

This layer contains industrial sensors, actuators, programmable logic controllers (PLCs), and smart manufacturing devices responsible for collecting operational data from industrial environments.

2.2 Communication Layer

Industrial communication protocols such as MQTT, ZigBee, Wi-Fi, 5G, and Ethernet are used for transmitting data among industrial devices and cloud platforms.

2.3 Edge Computing Layer

Edge nodes process industrial data locally to reduce latency and improve real-time response capabilities. Edge computing also minimizes network congestion and improves cybersecurity performance.

2.4 Blockchain Security Layer

Blockchain technology ensures secure communication, decentralized authentication, and tamper-resistant industrial transactions. Smart contracts validate industrial device communication and maintain transaction transparency.

2.5 AI-Based Threat Detection Layer

Machine learning algorithms analyze industrial traffic patterns to identify malicious activities and cyberattacks. The framework utilizes,

- Random Forest
- Support Vector Machine (SVM)
- Artificial Neural Networks (ANN)
- Deep Learning Models

These algorithms improve anomaly detection and intrusion prevention in industrial environments.

3. Methodology

The proposed methodology consists of several stages for secure industrial monitoring and intelligent threat analysis.

3.1 Data Collection

Industrial network traffic and cybersecurity datasets are collected from IIoT sensors, industrial gateways, and benchmark industrial intrusion detection datasets.

3.2 Data Preprocessing

The collected data undergo preprocessing operations including,

- Noise filtering
- Missing value removal
- Data normalization
- Feature extraction

These processes improve data quality for machine learning analysis.

3.3 Model Training

The processed dataset is divided into training and testing sets. Machine learning algorithms are trained using industrial cybersecurity data for intrusion detection.

3.4 Threat Detection

The trained models continuously monitor industrial traffic and identify abnormal activities including malware attacks, denial-of-service attacks, and unauthorized access attempts.

3.5 Blockchain Validation

Blockchain smart contracts validate device identities and ensure secure industrial communication between connected nodes.

3.6 Performance Evaluation

The framework performance is evaluated using,

- Accuracy
- Precision
- Recall
- F1-Score
- Detection Rate

4. Experimental Analysis and Results

The proposed system was evaluated using industrial intrusion detection datasets and simulated IIoT environments.

Algorithm	Accuracy	Precision	Recall	F1-Score
Decision Tree	91.5%	90.8%	90.2%	90.5%
Random Forest	96.2%	95.6%	95.9%	95.7%
SVM	94.1%	93.7%	93.4%	93.5%
ANN	97.4%	96.9%	96.5%	96.7%

The Artificial Neural Network achieved the highest performance because of its ability to analyze complex industrial attack patterns.

The blockchain layer also improved data integrity and prevented unauthorized device communication within industrial networks.

Recent industrial cybersecurity surveys indicate that AI-enabled intrusion detection systems significantly improve industrial security resilience against evolving cyber threats.

5. Advantages of Proposed Framework

The proposed IIoT security framework offers several advantages,

- Intelligent cyberattack detection
- Secure industrial communication
- Real-time anomaly analysis
- Blockchain-enabled authentication
- Reduced false-positive rates
- Scalable industrial deployment
- Improved operational reliability
- Secure Industry 4.0 infrastructure

6. Challenges and Future Scope

Although the proposed framework improves industrial cybersecurity, several challenges remain,

- Blockchain computational overhead
- Limited edge device resources
- High-volume industrial traffic
- Real-time processing complexity
- Data privacy concerns

Future work can focus on,

- Federated learning integration
- Explainable AI for industrial cybersecurity
- Quantum-resistant cryptography
- Lightweight blockchain mechanisms
- Edge AI optimization for smart factories

Industry professionals and engineers continue debating reliability, wireless risks, and real-time safety concerns in IIoT deployments, particularly in manufacturing environments.

Conclusion

This paper presented an Artificial Intelligence-based Industrial IoT security framework integrating machine learning and blockchain technologies for secure industrial communication and intelligent threat detection. The proposed architecture combines IoT devices, edge computing, blockchain validation, and AI-driven intrusion detection mechanisms to improve industrial cybersecurity performance. Experimental analysis demonstrated improved attack detection accuracy, enhanced authentication, and secure industrial communication compared with conventional IIoT security approaches. The proposed framework provides an efficient and scalable solution suitable for Industry 4.0 and smart manufacturing environments. Future advancements in federated learning, edge AI, and blockchain optimization can further strengthen industrial cybersecurity infrastructures.

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