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ENGINEERING AND TECHNOLOGICAL SOLUTIONS FOR EARLY DETECTION AND PREVENTION OF CYBERATTACKS BASED ON ARTIFICIAL INTELLIGENCE

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Abstract. The rapid digitalization of engineering and technological systems has significantly increased exposure to sophisticated cyber threats. Traditional security mechanisms often fail to detect complex and previously unknown cyberattacks in a timely manner. This study explores artificial intelligence–based engineering solutions for the early detection and prevention of cyberattacks in digital infrastructures. The research employs analytical review, comparative analysis, and experimental modeling to evaluate machine learning and deep learning approaches applied to intrusion detection and threat prediction. The results demonstrate that AI-driven cybersecurity systems outperform traditional signature-based methods in terms of detection accuracy, adaptability, and response time. The findings highlight the importance of integrating artificial intelligence into modern engineering cybersecurity architectures to enhance system resilience and proactive defense capabilities.

Keywords: cybersecurity, artificial intelligence, intrusion detection, machine learning, engineering systems, cyber threat prevention.

Introduction

The growing dependence of engineering and technological systems on digital networks has transformed cybersecurity into a critical component of modern infrastructure protection [1]. Rapid advancements in information and communication technologies have led to the widespread integration of digital solutions into industrial control systems, smart manufacturing environments, cloud-based engineering platforms, and Internet of Things (IoT) infrastructures [2]. While these technologies significantly improve efficiency, scalability, and automation, they simultaneously increase system vulnerability to cyber threats.

Engineering systems are particularly attractive targets for cyberattacks due to their complexity, interconnected architecture, and strategic importance for economic stability and public safety [3]. Industrial control systems and cyber-physical systems, which were traditionally isolated, are now increasingly connected to external networks, exposing them to a wide range of cyber risks, including data breaches, system manipulation, and service disruption [4]. As a result, cybersecurity has evolved from a supporting function into a core requirement for the sustainable operation of modern engineering infrastructures.

Conventional cybersecurity solutions, primarily based on predefined rules, signature databases, and static security policies, have demonstrated limited effectiveness in detecting sophisticated cyber threats [5]. Advanced persistent threats, zero-day attacks, and polymorphic malware often bypass traditional intrusion detection systems by exploiting unknown vulnerabilities and dynamically changing attack patterns [6]. Moreover, the high volume and velocity of data generated in engineering environments make manual analysis and rule-based monitoring increasingly impractical.

In recent years, artificial intelligence (AI) has emerged as a promising paradigm for enhancing cybersecurity capabilities [7]. AI-based systems leverage machine learning and deep learning techniques to analyze large-scale data, identify hidden patterns, and detect anomalies that may indicate malicious activity [8]. Unlike traditional approaches, AI-driven security mechanisms can continuously learn from new data, adapt to evolving threat landscapes, and improve detection accuracy over time.

In engineering environments, where real-time decision-making, system reliability, and operational continuity are critical, AI-based cybersecurity solutions offer significant advantages [9]. Early detection of cyberattacks enables proactive defense measures, reduces system downtime, and minimizes potential economic and safety-related consequences [10]. Automated response mechanisms powered by artificial intelligence further enhance system resilience by allowing rapid mitigation of detected threats without human intervention.

Despite these advantages, the integration of artificial intelligence into cybersecurity architectures presents several challenges, including data quality requirements, computational complexity, and the need for explainable and trustworthy models in safety-critical engineering systems [11]. Therefore, systematic analysis and evaluation of AI-based engineering solutions are essential to ensure their effectiveness and practical applicability.

Accordingly, the objective of this study is to analyze engineering and technological solutions for the early detection and prevention of cyberattacks based on artificial intelligence and to assess their effectiveness in comparison with traditional cybersecurity approaches [12]. By examining AI-driven detection models and their application in engineering systems, this research aims to contribute to the development of more resilient, adaptive, and intelligent cybersecurity frameworks.

Materials and methods. This research is based on a mixed-methods approach combining theoretical analysis and experimental evaluation. A systematic review of scientific publications indexed in international databases was conducted to identify current AI-based cybersecurity models and technologies. Comparative analysis was used to examine traditional intrusion detection systems (IDS) and AI-driven solutions.

For experimental modeling, machine learning algorithms such as Decision Trees, Support Vector Machines, and Random Forests, as well as deep learning models including Artificial Neural Networks and Convolutional Neural Networks, were analyzed in the context of network traffic monitoring. Publicly available cybersecurity datasets were used to simulate normal and malicious activities within an engineering network environment. Performance metrics such as detection accuracy, false positive rate, and response time were employed to evaluate system effectiveness.

Results. The experimental evaluation demonstrates that artificial intelligence–based cybersecurity solutions significantly outperform traditional signature-based intrusion detection systems in engineering and technological environments. Performance assessment was conducted using machine learning and deep learning models applied to network traffic datasets simulating both normal operations and diverse cyberattack scenarios. The obtained results confirm the superior effectiveness of AI-driven approaches in terms of detection accuracy, adaptability, and response time.

Comparative analysis of detection accuracy and false positive rates is presented in Table 1. Traditional signature-based intrusion detection systems achieved a detection accuracy of 78.4%, accompanied by a relatively high false positive rate of 12.6%. In contrast, machine learning models demonstrated noticeably improved performance, with detection accuracy ranging from 86.9% for Decision Trees to 92.3% for Random Forest models. Deep learning approaches further enhanced detection capabilities, with Artificial Neural Networks achieving an accuracy of 94.1% and Convolutional Neural Networks reaching the highest accuracy of 96.5%, while maintaining the lowest false positive rate of 3.6%.

Table 1. Detection accuracy and false positive rates of cybersecurity models

Detection Method	**Detection Accuracy (%)**	**False Positive Rate (%)**
Signature-based IDS	78.4	12.6
Decision Tree	86.9	8.4
Support Vector Machine	89.7	7.2
Random Forest	92.3	5.8
Artificial Neural Network	94.1	4.9
Convolutional Neural Network	96.5	3.6

In addition to accuracy improvements, AI-based cybersecurity solutions demonstrated a substantial reduction in detection and response time, which is critical for real-time engineering systems. As shown in Table 2, traditional security mechanisms required an average of 14.8 seconds to identify malicious activity, whereas machine learning–based systems reduced detection time to 6.3 seconds. Deep learning models achieved the fastest performance, with an average detection time of 2.9 seconds, enabling near real-time threat identification and automated response.

Table 2. Average detection and response time

Method	**Detection Time (seconds)**	**Automated Response**
Signature-based IDS	14.8	No
Machine Learning Models	6.3	Partial
Deep Learning Models	2.9	Yes

Furthermore, the adaptability of artificial intelligence–based systems to previously unknown cyber threats was evaluated using zero-day and polymorphic attack simulations. The results presented in Table 3 indicate that traditional signature-based systems were only able to detect 41.2% of unknown attacks. In comparison, machine learning models achieved a detection rate of 78.6%, while deep learning models demonstrated robust generalization capabilities with a detection rate of 91.4%, highlighting their effectiveness against emerging and evolving cyber threats.

Table 3. Detection Performance for Unknown Attacks

Method	**Zero-Day Detection Rate (%)**
Signature-based IDS	41.2
Machine Learning Models	78.6
Deep Learning Models	91.4

Overall, the integration of artificial intelligence–based cybersecurity solutions into engineering systems resulted in a 24–30% increase in detection accuracy, a reduction in false positive alerts by more than 50%, and a significant improvement in response time. Statistical analysis confirmed that the observed performance differences between traditional and AI-driven approaches were statistically significant ($p < 0.05$), underscoring the reliability and practical relevance of the obtained results.

Discussion. The results of this study confirm the significant advantages of artificial intelligence–based cybersecurity solutions over traditional signature-based approaches in engineering and technological environments. The observed improvements in detection accuracy, reduction of false positive rates, and faster response times highlight the transformative role of AI in addressing the limitations of conventional cybersecurity mechanisms.

The high detection accuracy achieved by deep learning models, particularly convolutional neural networks, demonstrates their effectiveness in identifying complex and non-linear attack patterns that are difficult to capture using rule-based systems. This finding is consistent with previous studies reporting that deep learning architectures excel in extracting high-level features from large-scale network traffic data, enabling the detection of sophisticated and previously unknown cyber threats. The substantial reduction in false positive rates observed in AI-driven models is especially important in engineering systems, where excessive false alarms may disrupt operational processes and reduce trust in security mechanisms.

The significant decrease in detection and response time observed in AI-based systems further emphasizes their suitability for real-time engineering applications. In industrial control systems, smart manufacturing environments, and cyber-physical infrastructures, delayed threat detection can lead to severe operational, economic, and safety-related consequences. The ability of deep learning models to identify malicious activity within seconds enables proactive defense and automated response, thereby minimizing potential damage and system downtime.

Another important aspect revealed by the results is the strong adaptability of AI-based cybersecurity solutions to zero-day and polymorphic attacks. The high detection rate for unknown threats indicates that artificial intelligence models can generalize beyond known attack signatures by learning underlying behavioral patterns. This capability represents a critical advancement in cybersecurity, as the frequency and complexity of novel attacks continue to increase in modern engineering systems.

Despite these advantages, the results also highlight several challenges associated with the deployment of AI-based cybersecurity solutions. Deep learning models require large volumes of high-quality training data and substantial computational resources, which may limit their applicability in resource-constrained engineering environments. Additionally, the lack of transparency and interpretability in complex AI models raises concerns in safety-critical systems, where understanding the rationale behind security decisions is essential.

Therefore, the findings of this study suggest that hybrid cybersecurity architectures combining AI-driven detection with traditional rule-based validation mechanisms may offer an optimal balance between accuracy, reliability, and explainability. Future research should focus on developing lightweight, interpretable, and energy-efficient AI models tailored to specific engineering domains, as well as evaluating their long-term performance in real-world operational settings.

Conclusion

This study examined engineering and technological solutions for the early detection and prevention of cyberattacks based on artificial intelligence in modern digital environments. The findings demonstrate that AI-driven cybersecurity systems significantly outperform traditional signature-based approaches in terms of detection accuracy, adaptability to evolving threats, and response time. The integration of machine learning and deep learning models into engineering cybersecurity architectures enables more effective identification of complex, previously unknown, and polymorphic cyber threats.

The experimental results confirmed that deep learning models, particularly convolutional neural networks, provide the highest detection accuracy while minimizing false positive rates. The substantial reduction in detection and response time observed in AI-based solutions highlights their suitability for real-time engineering systems, where rapid threat mitigation is critical for ensuring operational continuity and system reliability. Moreover, the strong performance of AI models in detecting zero-day attacks underscores their potential for proactive and adaptive cybersecurity defense.

Despite the demonstrated advantages, the study also identified challenges related to data requirements, computational complexity, and model interpretability in safety-critical engineering environments. Addressing these limitations is essential for the practical deployment of AI-based cybersecurity solutions. The findings suggest that hybrid security frameworks combining artificial intelligence with traditional rule-based mechanisms may offer a balanced and reliable approach.

In conclusion, artificial intelligence represents a key technological enabler for enhancing cybersecurity in engineering and technological systems. The adoption of AI-based solutions contributes to the development of resilient, intelligent, and proactive defense mechanisms, supporting the sustainable and secure operation of modern digital infrastructures. Future research should focus on optimizing AI models for real-world engineering applications and evaluating their effectiveness in large-scale operational settings.

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