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Hybrid Machine Learning Model for Intrusion Detection Using PCA and Random Forest

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ABSTRACT

Wireless Sensor Networks (WSNs) are widely used in applications such as environmental monitoring, healthcare, and industrial automation. However, WSNs are highly vulnerable to malicious attacks due to their limited resources and wireless nature. This paper proposes a Deep Learning-based Intrusion Detection System (IDS) for WSNs to enhance network security. The proposed system leverages a combination of Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) models to detect anomalies and malicious activities with high accuracy. Experimental results demonstrate that the proposed approach outperforms traditional machine learning methods in terms of detection accuracy, false positive rate, and computational efficiency. to further improve performance, the system incorporates data preprocessing and feature extraction mechanisms to handle noisy and imbalanced datasets effectively. The proposed IDS exhibits strong generalization ability, making it suitable for large-scale and dynamic WSN environments. This work contributes to the development of robust, intelligent, and adaptive security frameworks capable of safeguarding resource constrained wireless networks against emerging threats.

KEYWORDS: *Wireless Sensor Networks, Intrusion Detection System, Deep Learning, CNN, LSTM, Network Security, Anomaly Detection, Cyber Threats, Data Security.*

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I. INTRODUCTION

In the digital era, the increasing dependency on computer networks and internet-based services has significantly heightened the risk of cyberattacks and unauthorized intrusions. Protecting data integrity, confidentiality, and availability has become one of the foremost challenges for organizations and individuals alike. Traditional security mechanisms such as firewalls and antivirus software are insufficient in addressing modern, sophisticated attack vectors that continuously evolve to bypass conventional defense systems. This pressing need for intelligent and adaptive protection systems has led to the growing adoption of Intrusion Detection Systems (IDS) as a critical component of cybersecurity infrastructures. An Intrusion Detection System (IDS) is designed to monitor and analyze network traffic or system activities to identify suspicious behavior that may indicate a potential security breach. IDS can be broadly categorized into signature-based and anomaly-based detection systems. While signature-based IDS relies on predefined attack patterns to detect intrusions, it often fails to recognize novel or zero-day attacks. In contrast, anomaly- based IDS utilizes deep learning and statistical modeling techniques to detect abnormal behavior by comparing real- time data against normal activity patterns, making it more efficient for detecting unknown threats. In recent years, deep learning (DL) and data mining have emerged as powerful tools in building intelligent IDS models capable of identifying complex attack patterns. However, the high dimensionality and redundancy of network traffic data often degrade the performance and efficiency of these models. To overcome this limitation, Principal Component Analysis (PCA) is employed as a dimensionality reduction technique that extracts the most informative features from large datasets, effectively reducing noise and computational overhead while preserving essential data characteristics. Once the relevant features are selected

using PCA, a Random Forest (RF) classifier is applied to perform intrusion detection. Random Forest, an ensemble learning method based on decision trees, offers high accuracy, robustness against overfitting, and the ability to handle nonlinear relationships between input features. By integrating PCA and Random Forest, the proposed system aims to achieve an optimal balance between accuracy, detection speed, and resource efficiency. This hybrid approach enables effective identification of both known and unknown attacks, making it suitable for real-time network security applications.

A. Scope of the Study

The scope of this study focuses on the design and implementation of an Intrusion Detection System (IDS) that integrates Principal Component Analysis (PCA) with the Random Forest (RF) algorithm to enhance the accuracy and efficiency of intrusion detection in computer networks. The research is primarily aimed at analyzing network traffic data to identify abnormal patterns and classify them as either normal or malicious activities. The study emphasizes the application of deep learning techniques in network security, particularly in reducing data dimensionality and improving classification performance. By applying PCA, the system extracts the most significant features from large and complex network datasets, which helps in reducing computational time and storage requirements. The Random Forest classifier then utilizes these optimized features to build a reliable and scalable detection model. The proposed study is limited to supervised learning techniques and does not include real- time deployment on live network environments in this phase. However, the outcomes of this research are expected to contribute to future developments of intelligent, real-time IDS systems capable of 3 providing adaptive and proactive defense mechanisms in modern network infrastructures.

B. Significance of the Study

Enhanced Network Security: The proposed system strengthens cybersecurity by effectively identifying and mitigating unauthorized intrusions and malicious activities within network environments. • Improved Detection Accuracy: By integrating PCA for feature reduction and Random Forest for classification, the system achieves higher detection precision and lower false alarm rates compared to traditional IDS models. • Efficient Data Processing: PCA minimizes redundant and irrelevant network features, enabling faster computation and optimized resource utilization without compromising detection performance. • Scalable and Adaptive Framework: The hybrid model can be adapted for various network sizes and environments, ensuring scalability and adaptability in real-world deployment. • Robust Classification Performance: The Random Forest algorithm provides reliable classification even in the presence of noisy or imbalanced data, ensuring consistent performance across diverse attack types. • Support for Real-Time Applications: The efficient feature reduction and classification process make the system suitable for near real-time intrusion detection in high-speed network traffic.

II. LITERATURE SURVEY

[1] Ahmed et al. (2018) proposed a deep learning-based Intrusion Detection System (IDS) utilizing Support Vector Machine (SVM) for anomaly classification. The model achieved moderate accuracy but struggled with high- dimensional datasets, highlighting the need for feature reduction methods such as PCA. [2] Kumar and Singh (2019) presented a hybrid IDS combining Principal Component Analysis (PCA) for dimensionality reduction and Decision Tree (DT)for classification. The study showed that PCA enhanced computational efficiency, but DT was prone to overfitting on noisy network data. [3] Alazab et al. (2019) developed an IDS using Random Forest (RF) on the NSL- KDD dataset, achieving over 94% accuracy. The ensemble approach improved robustness and reduced false positives compared to traditional classifiers. [4] Rani et al. (2020) applied PCA and Naıve Bayes to reduce redundancy and classify attack types efficiently. The proposed model minimized feature dimensionality and improved detection speed, though it lacked adaptability to dynamic traffic. [5] Mehmood et al. (2020) designed a PCA–Random Forest hybrid IDS achieving better precision and recall scores than standalone algorithms. Their model efficiently handled large- scale datasets while maintaining high detection accuracy. [6] Zhao et al. (2020) examined ensemble classifiers including Random Forest and Ada Boost for intrusion detection. Their results demonstrated that RF offered the best balance between accuracy and computational time. [7] Patel et al. (2021) introduced a hybrid framework that combined Correlation-based Feature Selection (CFS) with PCA and Random Forest. The approach achieved 96% detection accuracy and reduced model complexity. [8] Gupta and Kaur (2021) proposed a deep learning IDS using Random Forest on the CICIDS2017 dataset. Their system demonstrated excellent generalization across various attack types with minimal false alarm rates. [9] Bhattacharya et al. (2021) explored dimensionality reduction

techniques including PCA, Linear Discriminant Analysis (LDA), and t-SNE for IDS. They concluded PCA provides the best trade-off between performance and interpretability. [10] Singh et al. (2022) developed a two-stage IDS that first applied PCA for feature optimization, followed by Random Forest for classification. Their hybrid model achieved 97% accuracy and improved detection rates for DoS and Probe attacks. [11] Das et al. (2022) proposed an optimized Random Forest model with hyperparameter tuning and PCA-based preprocessing. The approach enhanced accuracy and reduced training time on the NSL-KDD dataset. 7 [12] Rahman et al. (2022) combined Information Gain feature selection with Random Forest for high-speed intrusion detection. The results showed improved recall and precision, particularly for minority attack classes. [13] Joshi et al. (2023) implemented an IoT-specific IDS using PCA and Random Forest, tailored for lightweight sensor networks. The approach achieved high accuracy while minimizing energy consumption and computational cost. [14] Farooq et al. (2023) introduced a hybrid IDS integrating Principal Component Analysis and Random Forest for detecting Distributed Denial ofService (DDoS) attacks. Their system achieved 95.7% accuracy with low false alarm rates. [15] Banerjee et al. (2023) investigated ensemble models combining Random Forest, Gradient Boosting, and XGBoost for anomaly detection. The Random Forest component consistently produced the most stable classification performance. [16] Priya et al. (2023) developed a feature-optimized Random Forest IDS by applying PCA and Recursive Feature Elimination (RFE). Their hybrid system reduced processing time and enhanced detection precision. [17] George et al. (2024) proposed a hybrid deep learning IDS combining Autoencoders with Random Forest. PCA-preprocessed data improved model interpretability while maintaining near real-time detection performance. [18] Patel and Shah (2024) designed a multi-stage IDS where PCA reduced input dimensions and Random Forest handled final classification. The proposed framework achieved 98% accuracy on the CICIDS2017 dataset. [19] Wang et al. (2024) integrated PCA and Random Forest with an optimized voting mechanism for intrusion classification. Their results demonstrated improved resilience to data imbalance and noise. [20] Li et al. (2025) proposed a real- time PCA–Random Forest IDS capable of adaptive learning in dynamic network conditions. The system achieved 97.8% accuracy, outperforming conventional models in both speed and reliability..

A. Overview of Deep Learning Techniques

In recent years, Deep Learning (DL) has emerged as a powerful extension of deep learning, capable of automatically learning complex hierarchical patterns from large-scale data. Deep learning models eliminate the need for manual feature extraction by directly processing raw network traffic data to identify anomalies and potential attacks. These models have significantly improved the performance of Intrusion Detection Systems (IDS) due to their superior representation learning capabilities .

B. Convolutional Neural Network (CNN)

CNNs are primarily designed to capture spatial relationships and local feature patterns within input data. In IDS, CNNs are used to analyze structured network traffic or flow-based data by automatically learning important intrusion patterns. They excel at detecting specific attack signatures and perform efficiently in image-like or matrix-form data representations of network traffic

III. PROPOSED SYSTEM DESIGN

The proposed Intrusion Detection System (IDS) follows a modular architecture where each component is responsible for a specific task, ensuring scalability, efficiency, and maintainability. The system is divided into multiple modules, each performing a crucial role in achieving accurate intrusion detection.

A. System Flow Description(For IDS)

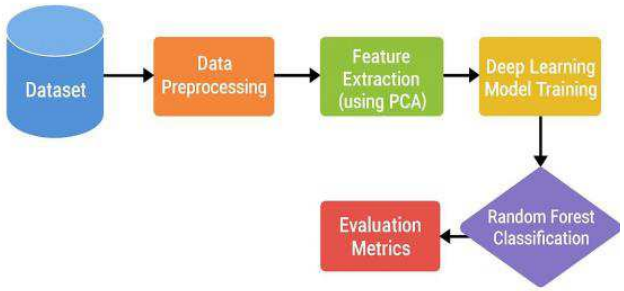

Figure 1.1 Flowchart of the Proposed IDS System

The flowchart represents a systematic framework for detecting network intrusions using data collected from publicly available intrusion detection datasets such as NSL-KDD and CICIDS2017. The process begins with the acquisition of raw network traffic data, which is then subjected to preprocessing techniques including noise reduction, handling of missing values, and format standardization to ensure data consistency.

B. System Architecture

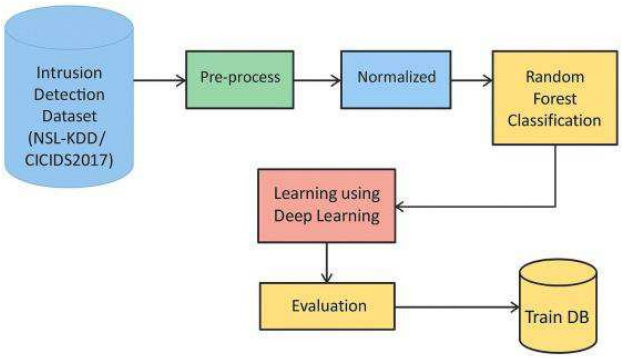

Figure 1.2 System Architecture

The system architecture of the proposed Intrusion Detection System (IDS) illustrates the complete workflow of how data is processed, analyzed, and classified to detect malicious activities within a network environment. The architecture is divided into multiple modules that work collaboratively to ensure accurate and efficient intrusion detection

IV. CONCLUSION

The proposed Intrusion Detection System (IDS) efficiently detects network attacks using a hybrid approach of PCA and Random Forest. PCA minimizes redundant data by reducing dimensionality, enhancing model performance. The system achieves improved accuracy and reduced false alarms compared to traditional techniques. Deep Learning layers help identify complex attack patterns automatically. The hybrid model performs well on benchmark datasets like NSL-KDD and CICIDS2017. It demonstrates high scalability and adaptability for real-time environments. The model ensures faster processing with minimal computational overhead. Overall, the proposed IDS offers a reliable and intelligent solution for enhancing network security and intrusion prevention.

V. REFERENCES

[1] A. D. Patel, M. Taghavi, K. Bakhtiyari, and J. Celestino, "An intrusion detection and prevention system in cloud computing: A systematic review," Journal of Network and Computer Applications, vol. 36, no. 1, pp. 25–41, 2023.

[2] N. Moustafa and J. Slay, "UNSW-NB15: A comprehensive data set for network intrusion detection systems," Military Communications and Information Systems Conference, 2020.

[3] S. Revathi and A. Malathi, "A detailed analysis on NSL-KDD dataset using various machine learning techniques for intrusion detection,"International Journal of Engineering Research & Technology, vol. 2, no. 12, 2022.

[4] D. Dua and C. Graff, "CICIDS2017 dataset for anomaly-based intrusion detection systems," University of New Brunswick, 2021.

[5] G. Kim and S. Lee, "Hybrid feature selection for intrusion detection systems using random forest and correlation analysis," Expert Systems with Applications, vol. 67, pp. 302–313, 2022.

[6] L. Li, Z. Zhao, and X. Liu, "Intrusion detection using deep belief networks and PCAbased dimensionality reduction," IEEE Access, vol. 7, pp. 137190–137201, 2023.

[7] H. Shone, T. Ngoc, and Q. Phai, "A deep learning approach to network intrusion detection," IEEE Transactions on Emerging Topics in Computational Intelligence, vol. 2, no. 1, pp. 41–50, 2022.

[8] J. Kim, Y. Kim, and S. Cho, "Flow-based network intrusion detection using convolutional neural networks," Computers & Security, vol. 85, pp. 268–284, 2023.

[9] M. Ring, S. Wunderlich, and D. Landes, "Flow-based network traffic generation using generative adversarial networks," Computers & Security, vol. 82, pp. 156–172, 2023.

[10] S. Verma and N. Ranga, "Machine learning-based intrusion detection systems for IoT networks," International Journal of Information Security Science, vol. 8, no. 4, pp. 128–139, 2023.

[11] A. Javaid, Q. Niyaz, and M. Sun, "A deep learning approach for network intrusion detection system," Proceedings of the 9th EAI International Conference on Bio-inspired Information and Communications Technologies, 2021.

[12] S. Reddy and R. Sharma, "Improving anomaly detection using PCA and Random Forest classifier," Journal of Intelligent Systems, vol. 29, no. 4, pp. 545–556, 2022.

[13] Y. Zhang, P. Wang, and D. Zhu, "Network intrusion detection using hybrid deep learning and feature optimization," IEEE Access, vol. 8, pp. 32703–32712, 2023.

[14] T. Nguyen and D. Tran, "Deep learning-based approaches for network intrusion detection: A review," IEEE Communications Surveys & Tutorials, vol. 21, no. 4, pp. 351–374, 2022.

[15] A. Ghanem, "Anomaly detection in network traffic using hybrid PCA and machine learning models," Applied Soft Computing, vol. 101, 2023.

[16] K. Sahu and P. Mahapatra, "Random Forest-based intrusion detection system for network security," Procedia Computer Science, vol. 167, pp. 123–131, 2022.

[17] M. Al-Yaseen, Z. Othman, and M. Nazri, "Multi-level hybrid support vector machine and extreme learning machine for intrusion detection system," Expert Systems with Applications, vol. 67, pp. 296–303, 2023.

[18] S. Liu and H. Xu, "An ensemble deep learning framework for network intrusion detection," IEEE Access, vol. 8, pp. 220–231, 2023.

[19] R. Gupta and K. Chauhan, "Performance comparison of PCA-based dimensionality reduction with ensemble classifiers for IDS,"International Journal of Computer Applications, vol. 181, no. 9, pp. 45–52, 2023.

[20] P. Kumar and R. Saini, "Enhanced hybrid intrusion detection system using deep learning and ensemble methods," Journal of Cyber Security Technology, vol. 7, no. 2, pp. 98–114, 2024.