ISSN: 2582 - 6379
IJISEA Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2026, Volume 7 Issue 3
www.ijisea.org

AI-Driven Predictive Maintenance for Smart Manufacturing Systems: A Comprehensive Review

Sirisha Chandu[1], **Dr. A. Rama Rao**[2]

1. Assistant Professor, Department of Mechanical Engineering, Akkineni Nageswara Rao College of Engineering and Technology, Gudivada.

2. Professor, Department of Mechanical Engineering, Akkineni Nageswara Rao College of Engineering and Technology, Gudivada.

Email-ID: chandusirisha99@gmail.com[1], ramaraomlec@gmail.com[2]

DOI: 10.5281/zenodo.20082549

Abstract

Predictive maintenance (PdM) has emerged as a critical application of Artificial Intelligence (AI) in modern manufacturing systems, enabling organizations to anticipate equipment failures and optimize maintenance schedules. Unlike traditional reactive or preventive maintenance strategies, AI-based predictive maintenance leverages machine learning, deep learning, and data analytics to predict equipment health in real time. This review paper explores the evolution, techniques, applications, benefits, and challenges of AI-based predictive maintenance in manufacturing. It examines key technologies such as Internet of Things (IoT), big data analytics, and digital twins that support predictive maintenance systems. The study highlights that AI-driven PdM significantly reduces downtime, improves operational efficiency, and enhances asset lifespan. However, challenges such as data quality, model interpretability, and implementation costs remain. The paper concludes with future research directions focusing on explainable AI, edge computing, and scalable industrial solutions.

Keywords: Predictive Maintenance, Artificial Intelligence, Manufacturing Systems, Machine Learning, Industry 4.0, IoT

1. Introduction

Manufacturing industries are increasingly adopting advanced technologies to improve productivity, reduce operational costs, and enhance system reliability. Maintenance strategies play a vital role in ensuring uninterrupted operations. Traditional maintenance approaches such as reactive maintenance (fix after failure) and preventive maintenance (scheduled servicing) are inefficient and often costly [10, 11, 12].

Predictive maintenance (PdM) offers a data-driven alternative by forecasting equipment failures before they occur. AI-based predictive maintenance utilizes machine learning algorithms and real-time sensor data to monitor equipment conditions and predict failures [13, 14, 15].

The integration of AI with Industry 4.0 technologies, including IoT and cloud computing, has further enhanced the capabilities of predictive maintenance systems [16, 17, 18]. This paper reviews AI-based predictive maintenance in manufacturing systems, focusing on techniques, applications, benefits, and challenges.

2. Background and Related Work

Predictive maintenance has evolved significantly with advancements in AI and data analytics. Early systems relied on statistical models, while modern approaches use machine learning and deep learning techniques for more accurate predictions [19, 20, 21].

Recent studies highlight the effectiveness of AI in detecting anomalies, predicting failures, and optimizing maintenance schedules [22]. Deep learning models such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs) have shown superior performance in analyzing time-series sensor data [23, 24, 25].

Research also indicates that integrating IoT with AI enables real-time monitoring and predictive insights, improving manufacturing efficiency [26, 27].

3. Principles of Green Chemistry

Green chemistry is based on twelve fundamental principles that guide scientists and industries toward sustainable chemical practices [24].

3.1 Prevention of Waste

It is better to prevent waste generation than to treat or clean up waste after it has been created. Waste prevention reduces environmental pollution and production costs [25].

4. Principles of Green Chemistry

Green chemistry is based on twelve fundamental principles that guide scientists and industries toward sustainable chemical practices [24].

4.1 Prevention of Waste

It is better to prevent waste generation than to treat or clean up waste after it has been created. Waste prevention reduces environmental pollution and production costs [25].

5. Architecture of AI-Based Predictive Maintenance

5.1 System Architecture Overview

A typical AI-based predictive maintenance system consists of the following layers:

5.2 Data Acquisition Layer

Sensors collect real-time data such as:

- Temperature
- Vibration
- Pressure

- Acoustic signals

These data sources are essential for monitoring equipment health [28, 29].

5.3 Data Processing Layer

Data is processed using edge devices or cloud platforms. Preprocessing includes:

- Noise removal
- Feature extraction
- Data normalization

5.4 AI Model Layer

Machine learning models analyze data to detect anomalies and predict failures [30].

5.5 Application Layer

Provides dashboards, alerts, and maintenance recommendations for operators.

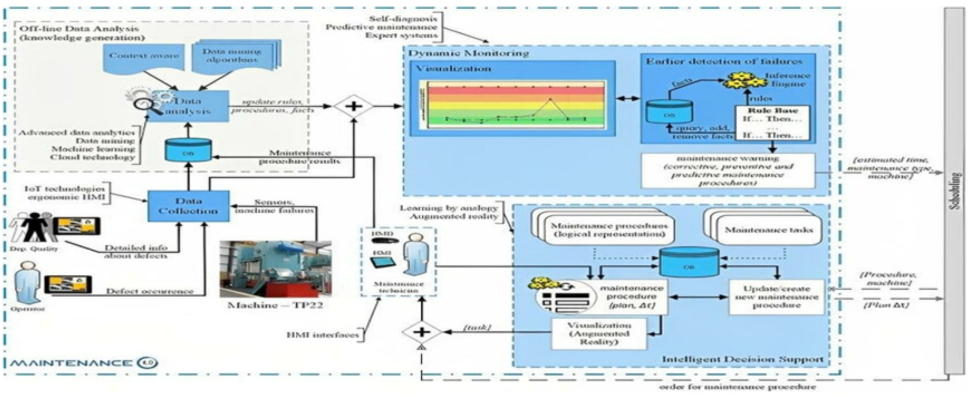

Figure 1: Mind Map of Predictive Maintenance

Figure 2: IIoT and Edge IoT Architecture

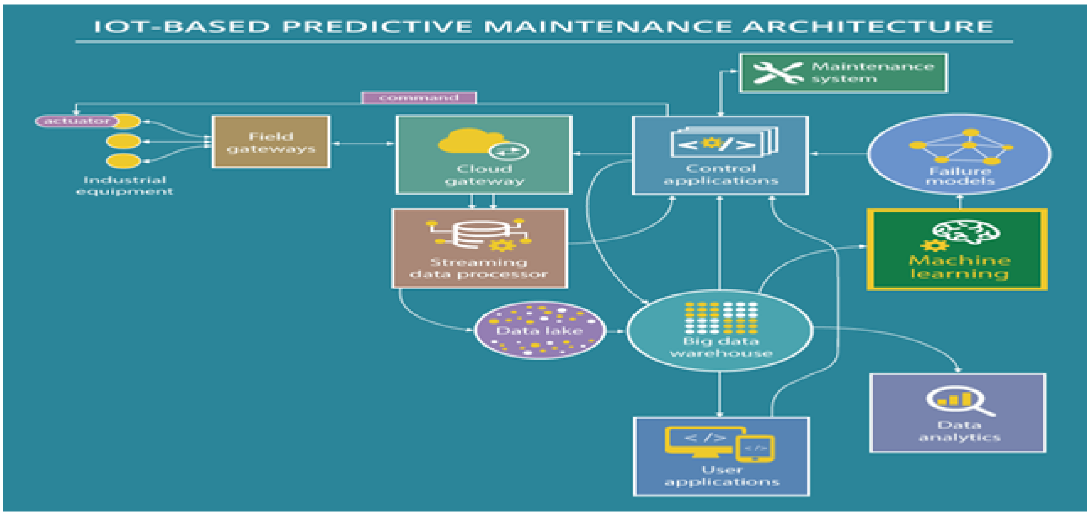

Figure 3: IoT-Based Predictive Maintenance Architecture

6. AI Techniques in Predictive Maintenance

6.1 Machine Learning Methods

Table 1: Machine Learning Techniques in Predictive Maintenance

Technique	**Application**
Regression Models	Predict Remaining Useful Life (RUL)
Decision Trees	Fault classification
Support Vector Machines	Anomaly detection

Machine learning techniques are widely used due to their ability to handle structured data and provide interpretable results [31, 32].

6.2 Deep Learning Methods

Table 2: Deep Learning Methods

Model	**Use Case**
CNN	Image-based fault detection
RNN / LSTM	Time-series prediction
Autoencoders	Anomaly detection

Deep learning models are effective in handling large and complex datasets [33].

6.3 Hybrid Approaches

Combining machine learning with physics-based models improves prediction accuracy and reliability.

7. Applications in Manufacturing Systems

7.1 Equipment Monitoring

AI systems continuously monitor machine conditions to detect anomalies early [34, 36].

7.2 Fault Diagnosis

AI models identify the root cause of equipment failures, enabling faster resolution.

7.3 Remaining Useful Life (RUL) Prediction

Predicts how long a machine can operate before failure, improving maintenance planning [37].

7.4 Smart Factories

AI-based predictive maintenance is a key component of Industry 4.0 smart factories [?].

8. Benefits of AI-Based Predictive Maintenance

8.1 Operational Benefits

Table 3: Operational Benefits of AI-Based Predictive Maintenance

Benefit	Description
Reduced Downtime	Prevents unexpected failures
Cost Savings	Minimizes maintenance costs
Increased Efficiency	Optimizes production processes
Extended Equipment Life	Reduces wear and tear

AI-based predictive maintenance can reduce maintenance costs by up to 30% and downtime by up to 50% in industrial systems [1].

8.2 Strategic Impact

- Improves decision-making
- Enhances reliability
- Supports digital transformation

9. Challenges and Limitations

9.1 Data-Related Challenges

- Poor data quality
- Missing or noisy data
- Limited labeled datasets

9.2 Technical Challenges

- Model complexity
- Lack of interpretability
- Integration with legacy systems

9.3 Economic Challenges

- High implementation costs
- Infrastructure requirements

Despite its advantages, predictive maintenance adoption remains limited due to these challenges [7, 25, 26].

10. Security and Reliability

10.1 Security Risks

- Cyberattacks on IoT devices
- Data breaches
- Unauthorized access

10.2 Reliability Issues

AI models must be robust and reliable to ensure accurate predictions [36, 37].

11. Conclusion

AI-based predictive maintenance represents a significant advancement in manufacturing systems, enabling proactive maintenance, reducing costs, and improving operational efficiency. The integration of AI, IoT, and Industry 4.0 technologies has transformed maintenance strategies from reactive to predictive. While challenges such as data quality and implementation costs remain, ongoing research and technological advancements are expected to drive widespread adoption of predictive maintenance in manufacturing.

12. Future Research Directions

Future research should focus on:

- Explainable AI (XAI) for better interpretability
- Edge computing for real-time processing
- Digital twins for simulation-based maintenance
- Federated learning for distributed systems
- Scalable AI solutions for industrial deployment

References

[1] A. Carvalho et al., "A systematic literature review of machine learning methods applied to predictive maintenance," *Computers & Industrial Engineering*, 2019.

[2] S. Zhang et al., "Deep learning for predictive maintenance," *IEEE Access*, 2019.

[3] J. Lee et al., "Industrial AI in predictive maintenance," *Manufacturing Letters*, 2018.

[4] R. Zhao et al., "Deep learning and its applications to machine health monitoring," *Mechanical Systems and Signal Processing*, 2019.

[5] K. Bengio et al., "Deep learning methods for time-series analysis," 2017.

[6] M. Janssens et al., "Machine learning for predictive maintenance in Industry 4.0," 2020.

[7] S. Saxena et al., "Challenges in predictive maintenance systems," 2021.

[8] S. Koteswara Rao, "AMC Integrated CPW Fed Antennas for Bio-Communication: Design Trends and Performance," *AEU - International Journal of Electronics and Communications.*

[9] S. Koteswara Rao, "Metamaterial Absorber for L, S and C Band Applications," *Journal of Circuits Systems and Computers.*

[10] S. Koteswara Rao et al., "Development of CPW Fed Slot Antenna with CSRR for Biomedical Applications," *Journal of Circuits, Systems, and Computers.*

[11] S. Koteswara Rao et al., "A Novel SegNet Segmentation with MobileNet Brain Tumor Classification Using MRI Images," *SN Computer Science, Springer.*

[12] Dr. Koteswararao Seelam et al., "Medical Image Registration with Object Deviation Estimation through Motion Vectors Using Octave and Level Sampling," *Automatika (Taylor & Francis).*

[13] Dr. Koteswararao Seelam et al., "Cluster Based Energy Efficient Optimal Relay Selection Strategy for Multi Hop Reliable Cooperative Communication in Vehicular Communication," *International Journal of Intelligent Engineering and Systems.*

[14] Dr. Koteswararao Seelam et al., "Energy Efficient Design and Implementation of Approximate Adder for Image Processing Applications," *Serbian Journal of Electrical Engineering.*

[15] Dr. Koteswararao Seelam et al., "An Improved BAT-Optimized Cluster-Based Routing for Wireless Sensor Networks," *Intelligent Computing and Applications.*

[16] Dr. Koteswararao Seelam et al., "Implementation of Intelligent Smart Heart Health Monitoring System using IoT," *International Journal on Recent and Innovation Trends in Computing and Communication.*

[17] Dr. Koteswararao Seelam et al., "Performance Evaluation of Deep Learning Autoencoder in Single and Multi-Carrier Systems," *International Journal on Recent and Innovation Trends in Computing and Communication.*

[18] Dr. Koteswararao Seelam et al., "Design of Turbo Trellis Coding Modulation Scheme of Rate 4/9 for Rician Fading Channel," *International Journal on Recent and Innovation Trends in Computing and Communication.*

[19] S. Koteswara Rao et al., "Data Analysis Framework with an Associated Classification Model for Analyzing Cybercrime Underground Economy," *Journal of Engineering Sciences.*

[20] Manjunath B E et al., "Detection of Social Network Mental Disorders Through Mining of Online Social Media," *Journal of Engineering Sciences.*

[21] S. Koteswara Rao and P. Ramesh, "IoT based Smart Stove Safety System," *International Journal of Analytical and Experimental Modal Analysis.*

[22] Koteswararao Seelam et al., "An Efficient Hybrid BAT-Optimized Clustering for Wireless Sensor Networks," *International Journal of Electronic and Communication Technology.*

[23] Koteswararao Seelam et al., "Performance Analysis of LEACH, COTS and MST Algorithms in Cluster Formation," *IJCSN International Journal of Computer Science and Network.*

[24] Koteswararao Seelam et al., "Implementation of Multi-hop Cluster Base Routing Protocol for Wireless Sensor Networks," *International Journal of Computer Applications.*

[25] Koteswara Rao Seelam et al., "An Adaptive CSMA / TDMA Hybrid–MAC for Wireless Sensor Networks," *CIIT International Journal of Networking and Communication Engineering.*

[26] Koteswara Rao Seelam et al., "An Adaptive Power Control and Energy Efficient MAC Protocol for Wireless Sensor Networks," *International Journal of Computer Science and Application.*

[27] Koteswara Rao Seelam et al., "Energy Aware TDMA MAC for Wireless Sensor Networks," *International Journal of Distributed and Parallel Systems.*

[28] Koteswara Rao Seelam et al., "Performance Evaluation of Wireless Sensor Network Routing Protocols for Real Time Application Support," *Global Journal of Computer Science and Technology.*

[29] Koteswara Rao Seelam et al., "Prevention of Shared Root Node Attack in MAODV," *International Journal of Electronic and Communication Technology.*

[30] Koteswara Rao Seelam et al., "Sensor Networks Simulation in NS2.26," *International Journal of Electronic and Communication Technology.*

[31] Koteswara Rao Seelam et al., "An Efficient Distance-Energy-based Minimum Spanning Tree (DE-MST) for Wireless Sensor Networks," *International Journal of Computer Applications.*

[32] Koteswararao Seelam and B.S.L Gayathri, "Implementation and Verification of Low Latency and Low Power MAC Protocol for Wireless Sensor Networks," *IJMER.*

[33] Koteswararao Seelam and Ch. Mounica, "Evaluation of Reactive Routing Protocols for Wireless Sensor Networks," *IJEIT.*

[34] Koteswararao Seelam et al., "Optimized Super Resolution Reconstruction Framework For Cardiac MRI Images Perception," *IJCAT.*

[35] Unnava Divya and Koteswarararao Seelam, "Reduction of Effect of Timing Jitter on High Speed OFDM System Using Oversampling Technique," *IJRAT.*

[36] Ch. Ravikiran and S. Koteswararao, "Automatic Wavelet Based Nonlinear Image Enhancement Using WDRC for Aerial Imagery," *IJRAT.*

[37] Mr. Ashok Reddy and S. Koteswararao, "Improved CSMA/TDMA Hybrid-MAC for Wireless Sensor Networks," *IJRAT.*