

An Integrated AI-Driven Framework for Enhancing Quality, Reliability, and Predictive Maintenance in Smart Manufacturing Systems

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Abstract

In modern manufacturing environments, ensuring high product quality while maintaining system reliability and minimizing downtime remains a critical challenge. The increasing adoption of Industry 4.0 technologies has generated large volumes of operational data, creating new opportunities for intelligent decision-making in quality control and maintenance management. This paper proposes an integrated AI-driven framework that simultaneously enhances quality performance, system reliability, and predictive maintenance effectiveness in smart manufacturing systems. The proposed framework combines statistical quality control, reliability engineering models, and machine learning techniques to detect quality deviations, predict equipment failures, and optimize maintenance actions. Historical production and condition-monitoring data are analyzed using advanced machine learning algorithms to estimate failure probabilities, identify critical quality parameters, and support proactive maintenance planning. Reliability indicators such as Mean Time Between Failures (MTBF) and failure rates are incorporated to align maintenance decisions with quality improvement objectives. A case study from a manufacturing system demonstrates the applicability and effectiveness of the proposed framework. The results show significant improvements in product quality consistency, system availability, and maintenance efficiency compared to traditional reactive and preventive approaches. The proposed approach provides industrial engineers and decision-makers with a practical and scalable solution for integrating quality, reliability, and maintenance in data-driven manufacturing environments.

Keywords

Quality Engineering; Reliability Analysis; Predictive Maintenance; Machine Learning; Industry 4.0; Smart Manufacturing.