Intelligent Quality Control in Manufacturing Using Integrated Statistical Process Control and Machine Learning

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Abstract

This paper presents an integrated framework combining Statistical Process Control (SPC) and Machine Learning (ML) to enhance quality monitoring and productivity in CNC manufacturing processes. The study focuses on a shaft diameter machining process using a dataset of N production batches, where diameter is considered as the critical quality characteristic and tool wear, pressure, and temperature are treated as input variables. SPC techniques, specifically Individuals and Moving Range (I–MR) control charts, are applied to evaluate process stability and identify variations such as mean shifts and abnormal fluctuations. Process capability analysis is performed using Cp and Cpk indices to assess conformance with specification limits.To enable predictive analysis, a multiple linear regression model is developed to establish relationships between process parameters and output quality, followed by a Random Forest model to improve prediction accuracy and determine feature importance. The results indicate that the process is partially capable and that tool wear is the most significant factor influencing diameter variation. The proposed SPC–ML integration provides both statistical monitoring and predictive insights, enabling early detection of deviations, root cause identification, and data-driven decision-making. This approach supports improved process control, reduced variability, and enhanced production efficiency in modern manufacturing systems.

Keywords

Statistical Process Control, Machine Learning, CNC Manufacturing, Process Capability, Predictive Quality Control.