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A Scalable IoT-Driven Framework for Predictive Maintenance Using Big Data Analytics and Machine Learning

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The reliance on conventional industrial maintenance strategies like reactive and preventive maintenance leads to unexpected production halts, unnecessary costs, and reduced equipment efficiency. This proposed work addresses these inefficiencies by developing a scalable predictive maintenance (PdM) system for industrial machines, specifically lathe machines. It leverages real-time data from low-cost sensors and advanced deep learning models to monitor parameters such as vibration, temperature, and current using an ESP32 microcontroller. The primary contribution is the implementation of a fault-tolerant architecture utilizing Message Queuing Telemetry Transport (MQTT), Apache Kafka for high-volume message buffering, and Apache Spark for real-time data pre-processing. Another identified gap is the development of an effective AI-based model for predicting machine condition. To address this, a Patch Time-Series Transformer (PatchTST) model is employed rather than a traditional Long-Short-Term-Memory (LSTM) model, which processes 30 days of historical readings (720 past hourly timesteps as the lookback which is the context used by the model) to forecast the next 5 days (120 future hourly timesteps as the horizon which is the forecast prediction time period by the model). Experimental results demonstrate high predictive accuracy, with the 'current' feature achieving 91.89%, 'vibration' at 81.46%, 'body temperature' at 70.51%, and 'shaft temperature' at 86.49%. The goal of implementing this framework is to potentially reduce equipment downtime by approximately 25% based on forecasting-led proactive interventions. This integrated approach provides a robust, cost-effective solution for real-time industrial condition monitoring.

Keywords: Deep learning, Artificial Intelligence, Predictive Maintenance, Transformers, Timeseries Forecasting, Big Data Scalability