Erasmus Mundus Joint Master in Manufacturing 4.0 by intElligent and susTAinable technologies

meta4.0

MASTER's Degree Thesis

Development of a Multi-Sensor Signal Processing and Machine Learning System for Predicting Hole Quality in Aerospace Drilling

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Abstract:

When it comes to traditional machining operations, drilling is one of the basic ones, alongside turning or milling. In aerospace assembly, factories still rely on human operators to drill holes in locations unreachable by robots or automated units. While this flexibility is essential, it comes at a cost: hole quality varies with operator skill, access, and posture, making it difficult to meet strict aerospace tolerances. At the same time, advances in sensors, artificial intelligence, and Industry 4.0 practices create opportunities for data-driven systems that improve consistency in these processes. This thesis develops a monitoring and prediction framework for aerospace drilling, with a focus on manual operations. A sensor-based prototype was designed to capture real-time process inputs by extracting feed rate and cutting speed per depth through dedicated signal-processing and fusion methods. Hole quality was quantified using spectral decomposition with Tivoly's Hole Detective tool, separating enlargement, circularity, ovalisation, and trilobe defects. Controlled CNC/ADU trials and manual drilling tests on aluminium workpieces generated datasets for training and evaluation. Machine learning models were tailored to process stability. For CNC/ADU data, a physics informed modular neural network achieved high predictive accuracy, with R^2 values above 0.90 for enlargement and trilobe and solid performance for circularity and ovalisation. For manual drilling, where variability and noise were greater ensemble methods were examined. XGBoost performed best, reliably predicting enlargement ($R^2 \approx 0.84$) and capturing useful trends in circularity, though predictions for ovalisation and trilobe were less accurate when defect values were small. The results show that intelligent monitoring of manual drilling is feasible. By combining sensor fusion, spectral analysis, and machine learning, manual drilling can be linked to geometric outcomes under variable conditions, reducing rework, improving reliability, and supporting the goals of Industry 4.0.

Keywords: Aeronautic drilling, Sensor fusion, Hole quality prediction, Machine learning

September 2025