Quantum Machine Learning for Defect Detection and

Quality Assurance in High-Throughput Manufacturing

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***Abstract*—As manufacturing systems advance toward higher throughput, tighter tolerances, and increasingly complex quality requirements, traditional defect detection and quality assurance methods struggle to scale effectively. Quantum Machine Learning (QML) offers a new computational paradigm capable of capturing high-dimensional feature interactions, accelerating pattern recognition, and improving anomaly detection in industrial environments. This study investigates the integration of quantum kernel methods, variational quantum classifiers, and hybrid quantum–classical neural architectures for real-time defect identification across optical, acoustic, and sensor-rich inspection systems. The proposed framework leverages the expressivity of quantum feature spaces to enhance classification fidelity while maintaining compatibility with existing digital manufacturing pipelines. Experimental simulations demonstrate that QML models achieve notable improvements in detecting subtle surface irregularities, micro-defects, and non-linear process deviations when compared to conventional deep learning baselines. These findings underscore the potential of quantum-enhanced analytics to redefine quality assurance strategies in high-throughput manufacturing, enabling earlier defect localization, lower false-negative rates, and more resilient production workflows.**

Quality assurance in high-throughput manufacturing has become increasingly challenging as production environments grow more complex, data-intensive, and precision-driven. Traditional machine learning and deep learning methods have significantly advanced automated defect detection; however, they often face limitations when dealing with high-dimensional sensor data, non-linear feature relationships, and subtle defect signatures embedded in multimodal datasets [3]. As product complexity increases—from microelectronics to additive manufacturing components—the shortcomings of classical approaches become more pronounced, leading to false negatives, unreliable classification boundaries, and bottlenecks in real-time inspection workflows [6].

Recent developments in quantum computing present an opportunity to reimagine quality assurance through Quantum Machine Learning (QML). Unlike classical models that rely on polynomial-scale feature transformation, QML algorithms leverage quantum state superposition and entanglement to efficiently represent exponentially large feature spaces [7]. This capability is particularly beneficial for manufacturing datasets exhibiting complex spatial–temporal correlations, such as hyperspectral

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