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A calibrated ensemble framework for multi-class defect evaluation in ceramic sanitaryware manufacturing

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ABSTRACT

Reliable defect evaluation is essential in ceramic sanitaryware manufacturing, where inspection outcomes directly influence rework decisions, process control, and delivery performance. In practice, defect assessment is often affected by operational variability, class imbalance, and human-dependent inspection procedures, which limit the repeatability and consistency of quality control decisions. This study formulates multi-class defect classification as a practical quality control problem and investigates the robustness of production-data-based decision-support in an industrial environment. The analysis is based on a real-world dataset comprising 11,071 production records collected under routine operating conditions. Defect labels were assigned through a two-stage quality control procedure involving trained inspectors and supervisory verification. Multinomial logistic regression, support vector machines with radial basis function kernels, and CatBoost were evaluated as base classifiers. A probability-based voting ensemble was developed to integrate the complementary decision structures, and posterior probabilities were calibrated using Platt scaling prior to aggregation to improve decision consistency. Experimental results show that the proposed calibrated ensemble improves Macro-F1 from 0.7126 (logistic regression) to 0.7211 and enhances minority-class recall, leading to more balanced performance under severe class imbalance. The findings indicate that probability calibration and ensemble integration contribute to improved stability and interpretability of defect evaluation. Overall, the proposed framework provides a practically deployable decision-support layer that supports more consistent rework decisions and more reliable quality control in industrial production settings.

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