Development of a Real-Time YOLO-Based Defect Recognition and SPC System for PET Preforms: A Comparative Study of YOLOv11l and YOLOv26l

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Abstract:

Polyethylene terephthalate (PET) preforms are critical intermediate products in the beverage packaging industry. Defects generated during manufacturing may adversely affect blow-molding quality, product integrity, and customer satisfaction. Traditional manual inspection methods are limited by operator fatigue and subjective judgment, while the transparent nature of PET materials introduces challenges such as reflection, refraction, and low-contrast defects for automated optical inspection (AOI). To address these issues, this study develops a real-time artificial intelligence (AI)-based visual inspection and statistical process control (SPC) system for PET preforms. A multi-condition illumination framework was established to acquire 2,035 images under four illumination conditions, including red, green, blue, and white light. The dataset consists of five classes: specks, dust, scratches, bubbles, and normal samples. Two advanced object detection models, YOLOv11-Large (YOLOv11l) and YOLOv26-Large (YOLOv26l), were evaluated under identical training conditions. Experimental results indicate that YOLOv26l outperformed YOLOv11l in most defect categories, particularly for specks, scratches, and bubbles. For example, the Precision of scratch detection improved from 0.524 to 0.789, while the Precision of bubble detection increased from 0.776 to 0.891. In addition, Recall increased by 38.4% for specks and 7.9% for bubbles. The proposed framework further integrates SPC monitoring and supports future Agentic AI-based quality decision-making. The results demonstrate the feasibility of combining advanced computer vision and intelligent quality management technologies to achieve effective real-time quality control in PET preform manufacturing.

Keywords:

Computer Vision, Defect Detection, Polyethylene terephthalate (PET) preforms, Statistical Process Control.