Towards Inline Optical Assessment of Fiber-Web Uniformity Using Robust Image-Based Algorithms

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Abstract

Fiber-web uniformity describes the spatial distribution of material and may affect the appearance, mechanical properties and downstream processing of nonwoven products. Yet no universally accepted method exists for quantitative assessment. Conventional approaches such as cut-and-weigh testing are destructive, spatially limited and unsuitable for continuous monitoring. Camera-based measurement systems therefore enable objective, spatially resolved assessment within continuous production monitoring.
This study investigates image-based algorithms for evaluating the uniformity of unconsolidated fiber-webs under industrially relevant imaging conditions. Unlike earlier comparative studies that relied on abstract point-cloud or binary images, a controlled simulation framework was developed that combines adjustable homogeneity with explicit fiber-like structures by systematically varying generation parameters. It enables reproducible algorithm comparison while representing structural characteristics closely related to real fiber-web images. To assess the quality of the generated images, a user study was conducted in which domain experts were asked to distinguish simulated from real fiber-web images.

Subarea-based coefficient-of-variation and dispersion-index methods, binary and grayscale chi-square approaches, a surface-relief method and gray-level co-occurrence matrix features were evaluated using simulated images and recordings from an industrial line-scan camera system. The analysis considered variations in homogeneity, basis weight, image resolution, image size and preprocessing. The subarea-based coefficient-of-variation method and the grayscale chi-square approach exhibited the most consistent and robust behavior. In contrast, the binary chi-square method, the surface-relief approach and applied texture features were more sensitive to image representation, resolution and preprocessing.
Based on these findings, the selected method was implemented in an industrial camera-based measurement system and evaluated under production-oriented conditions. The resulting approach enables a differentiated and reproducible assessment of fiber-web uniformity and provides quantitative information for quality monitoring and process control. It supports the continuous detection of spatial inhomogeneities and the comparison of process states, thereby providing a basis for industrial quality assurance and data-driven process optimization.

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