22-263 Development of Deep Learning Based Nonwoven Uniformity Analysis

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Objective:

The main objective of this project is to develop a deep learning (DL) based framework for analyzing the uniformity of nonwoven fabrics. This framework aims to use convolutional neural networks (CNNs) and other DL techniques to detect defects and assess the uniformity of spunbond nonwoven fabrics. Ultimately, the goal is to create comprehensive DL models for nonwoven uniformity assessment.

Background:

Nonwoven fabrics play a critical role in a variety of industries, from healthcare to automotive, where the uniformity of the material significantly affects its aesthetic and physical properties, including permeability, tensile strength, and overall durability. To meet continuously growing needs for more uniform and high-quality nonwoven that can perform better even at lower basis weight and high productivity, the ability to precisely and comprehensively assess nonwoven uniformity becomes essential. However, the concept of nonwoven uniformity is one of the most ambiguously defined terms and involves multiple and complex aspects. Various uniformity methods were introduced but their results are not easy to interpret and can depend on imaging conditions and sample characteristics themselves. With recent advancements in Artificial Intelligence (AI) and Machine Learning (ML), particularly in the field of DL, there is a great opportunity to develop comprehensive and robust uniformity assessment methodology. This project aims to utilize these technologies to achieve more efficient and reliable fabric quality evaluation.

Problem Statement and Approach:

Nonwoven fabrics, with their complex structures and wide range of defect types and structural characteristics, require advanced analytical techniques for thorough examination. CNNs are particularly suited for this task because they can automatically learn and extract relevant features from large datasets, which is essential for identifying subtle structural irregularities in nonwoven materials. The approach involves building a custom CNN model trained on images of spunbond nonwoven fabrics, focusing on both defect detection and overall uniformity analysis. The system will be designed to function with minimal manual intervention and incorporate intelligent algorithms, making the quality control process more efficient.

Status:

The current stage of the project focuses on an extensive literature review on the development of CNN in DL. Key milestones in CNN research were analyzed, starting with the Neocognitron model in 1980, which laid the foundation of modern computer vision algorithms. LeNet, introduced by LeCun, was a pivotal model that enabled the applications of CNNs in real-world problems. A major breakthrough came with AlexNet in 2012, which revolutionized the use of CNNs in image classification and object detection, bringing CNN technology into the commercial use. Subsequent architectures, such as VGGNet and GoogLeNet, introduced deeper network layers to improve feature extraction capabilities. ResNet, introduced in 2015, solved the vanishing gradient problem, allowing for the training of much deeper networks through the introduction of residual connections. Recent advancements such as DenseNet, EfficientNet, Deformable Convolutional Networks, and Faster R-CNN have further enhanced the power and versatility of CNNs, making them indispensable in various fields of image analysis. The insights gained from these milestones are guiding the development of CNN models for nonwoven fabric analysis.

Key Issues:

The primary challenge of this project lies in accurately analyzing the intricate and varied structures of nonwoven fabrics. Additionally, the wide variety of defects, ranging from small irregularities to significant disruptions in the material's texture, adds much more complexity to defect detection. Another key issue is developing a CNN model that can generalize across various defect types without extensive manual tuning. Finally, ensuring that the model can efficiently process large-scale datasets and provide reliable assessments in real-time is a critical objective.

Next Steps:

The project is currently reviewing image processing methods, with a focus on CNNs. The next phase will continue the review, expanding to include recurrent neural networks (RNNs), Transformers, and their applications in defect detection. Simultaneously, the next step will involve collecting real and synthetic nonwoven fabric images to build a dataset for developing and testing deep learning models.