24-284SB Single-Shot Polarization Imaging of Defects in Fiber Spinning
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Objectives:

1. To implement a single-shot polarization imaging system on the Hills fiber spinning line to capture defects such as bubbles, polymer chain misalignments and surface roughness in real-time.
2. To compile a database of fiber polarization states (retardance and polymer chain alignment) for various polymer materials under different spinning parameters.
3. To develop and implement a machine learning-based automated process monitoring method for real-time defect detection and classification in single and multi-fiber spinning production.

Background:

Fiber spinning involves the rapid extrusion and stretching of polymer fibers, during which molecular alignment and crystallization occur. These processes define the mechanical and optical properties of the fibers. Irregularities in the fiber spinning process, such as surface roughness, molecular misalignments, and birefringence anomalies, can lead to weak points in the fibers, potentially resulting in defects in nonwoven materials. Monitoring the spinning process in real-time is essential for optimizing production parameters and ensuring consistent fiber quality. By integrating a high-speed single-shot polarization imaging system, it is possible to visualize these defects as they form, providing the data needed to prevent production errors and improve fiber properties.

Problem Statement and Approach:

Polymer fibers exhibit birefringent behavior, revealing internal stress distributions and molecular alignment through polarization imaging. Single-shot polarization imaging, combined with machine learning, offers a novel way to detect defects in real-time during high-speed fiber production. The use of a single-shot system will permit the system to operate at higher production rates and multi-fiber environments since only one image is used to calculate the polarization state. The system will be implemented on the Hills fiber spinning line and optimized for varying fiber diameters and production speeds, closer to industrial production conditions than previously demonstrated at NCSU for the multi-shot imaging system. An initial testing phase will involve the collection of baseline polarization data under different production parameters, followed by the development of a machine learning algorithm capable of defect detection in both single and multi-fiber production environments.

Status:

- A literature survey was conducted to analyze birefringence behaviors and defect formation during fiber spinning, including:
    - Molecular misalignment and surface roughness caused by high spinning speeds.
    - Irregular crystallization resulting in surface defects and stress concentrations.
- The single-shot polarization imaging system has been constructed and tested in a controlled environment.
- A database of fiber polarization states has been compiled for various production parameters.

Key Issues:

- The optimal position along the fiber extrusion line must be identified for system installation to ensure imaging of the most crystallized fiber state without losing focus due to fiber movement.
- The imaging system must be adjustable to accommodate different fiber diameters and spinning speeds.
- Large datasets of fiber defect images need to be collected for training the machine learning algorithm.

Next Steps:

1. Test the fiber response using dynamic tension measurements to collect high-speed polarization data.
2. Implement the single-shot polarization imaging system on the Hills fiber spinning line for trial imaging runs on single fibers.
3. Develop and refine a machine learning algorithm for automated real-time defect classification.