Polarimetric Flexible Endoscopy Utilizing an Imaging Fiber Bundle and a Pixelated Polarizer

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INTRODUCTION

Polarimetry for Biomedical Imaging: Previous studies and our own [1-2] have shown that polarimetry can provide contrast between cancerous and healthy tissue.

Clinical Translation: Standard of care involves using an endoscope to visually guide physical biopsy for histopathology. A flexible polarimetric endoscope could be effective for detecting abnormal tissue in gastrointestinal cancer, potentially eliminating or improving the guidance of physical biopsy.

Endoscopic Challenge: Flexible fiber bundles in endoscopes cause depolarization, making polarization data recovery difficult.

New Solution: We propose a simple, low-cost, scaleable polarimetric endoscope; a pixelated polarizer on a flexible imaging fiber bundle tip enables polarization data collection [3].

AIM

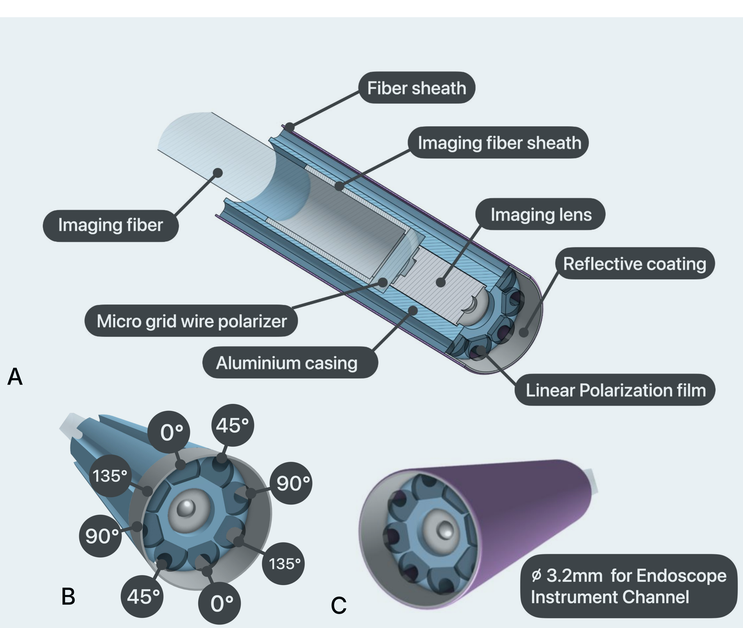

Figure 1: (A) A labeled cross-section of the polarimetric endoscope channel, (B) a front view of eight polarized illumination channels, and (C) a complete view of the instrument channel.

Polarization State Generator: 2x illumination fibers (∅400um) for each polarization state: 0°, 45°, 90°, 135 °

Polarization State Analyzer: Pixelated polarizer on imaging fiber bundle

POLARIZATION STATE ANALYZER

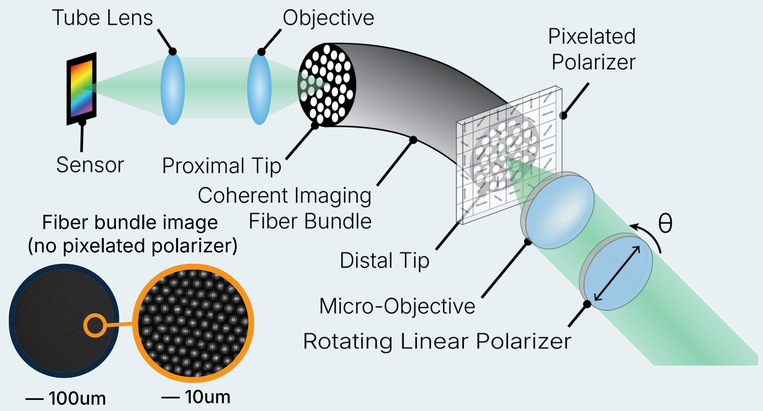

Figure 2: A labeled diagram illustrating the calibration process of the linear Stokes analyzer channel in the polarimetric endoscope. (not to scale)

Imaging Fiber Bundle:
Fiber Count = 30,000 fibers
Fiber Pitch = 4.5µm
Fiber Core Diameter = 2.9µm
Fiber Numerical Aperture = 0.35

Pixelated Polarizers:
(1) 5.5µm pitch (2) 7.4µm pitch
(3) 9.0µm pitch (4) 15.0µm pitch
Wire grid polarizer on SiO_2
Broadband with +/- 20° AOI without depolarization

FIBER POLARIZATION PROPERTIES

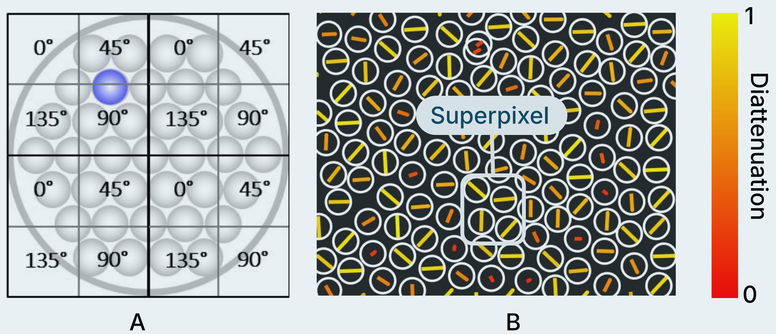

Figure 3: (A) A schematic of the pixelated polarizer placed on the imaging fiber bundle illustrates either a single micropolarizer or multiple micropolarizers (highlighted in blue) at each fiber location. (B) At each fiber position (depicted as a white circle), there is a line oriented according to the measured polarization angle. The length of this line is shaded to represent the measured diattenuation. A superpixel is created by grouping four fibers with linear polarization states that are 45° apart.

RESULTS

5.5um Pixel Pitch, Calibration Performed w/o Micro-Objective in Place

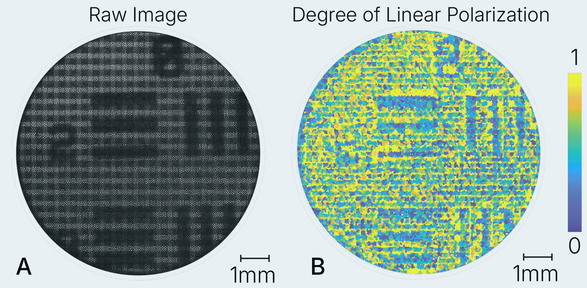

Figure 4: A raw image of a 1951 USAF target is captured at group 0, element 2-3 (A). The degree of linear polarization image is computed from calibration data for each fiber (B).

CONCLUSION & FUTURE WORK

- A pixelated polarizer on a flexible imaging fiber enables flexible polarimetric endoscopy
- **Algorithm** optimization and development for superpixel formation to balance fiber proximity, diattenuation, and polarization angle
- **Optomechanical design** for endoscope housing to ensure proper alignment of imaging and illumination systems
- **Manufacturing** with femtosecond laser ablation for cutting the pixelated polarizer

REFERENCES

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2) J. Bonaventura et al. Proc SPIE PC1284505 (2024).
3) N. Lima, and T. Sawyer. Proc. SPIE 1325801 (2024).

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