Design and Implementation of a Fiber-Based Endoscope for Fluorescence Lifetime Imaging in Cancer Diagnostics

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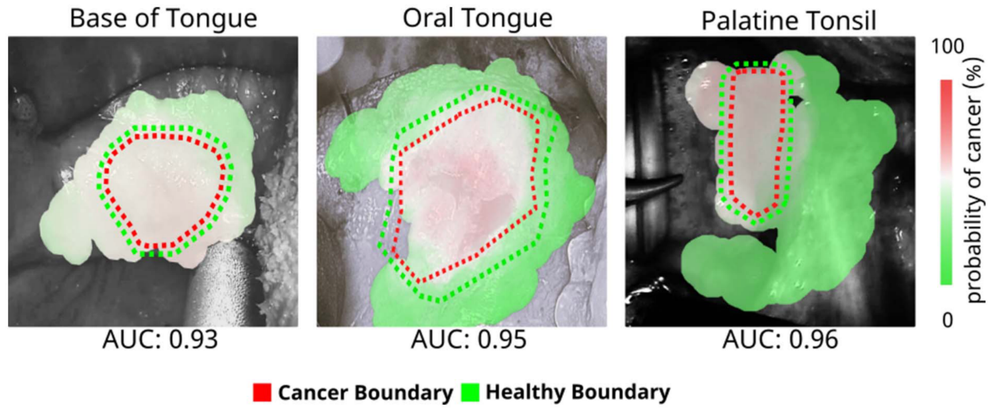
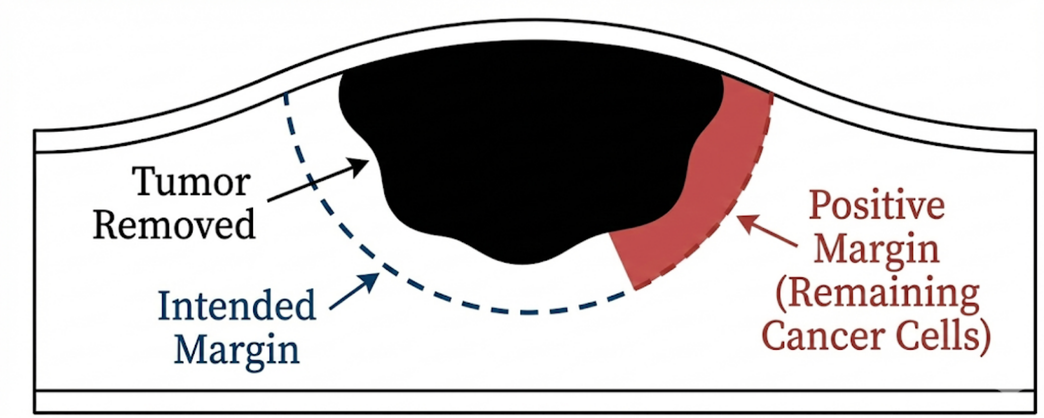
Why intraoperative margin detection matters ?

- Head and neck cancer → 70k deaths per year EU
- Surgeons misjudge margins in ~30% of cases
- Positive surgical margins remain common
- Need: objective, real-time intraoperative guidance

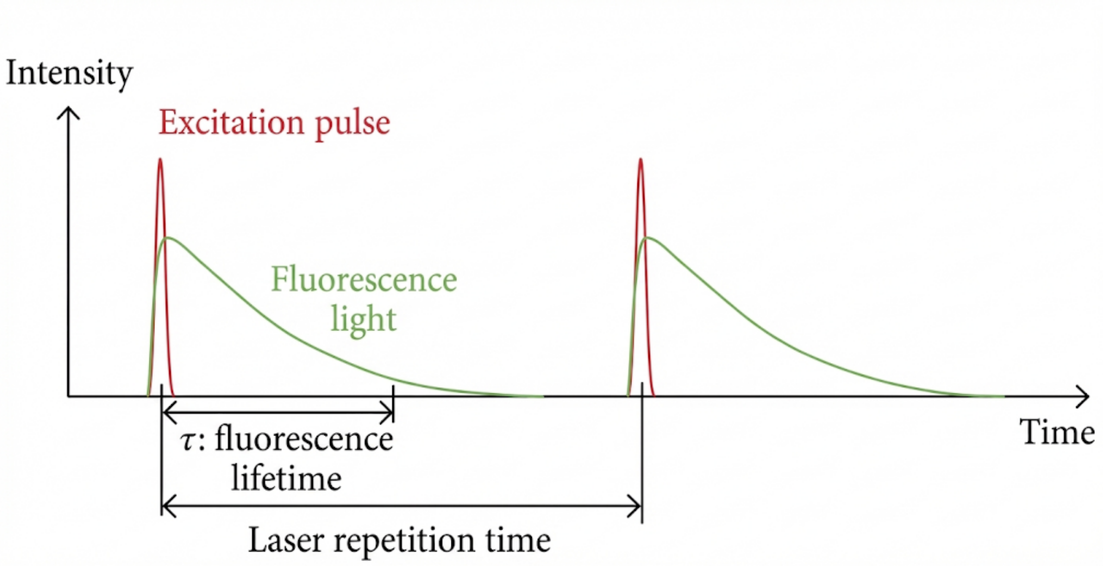


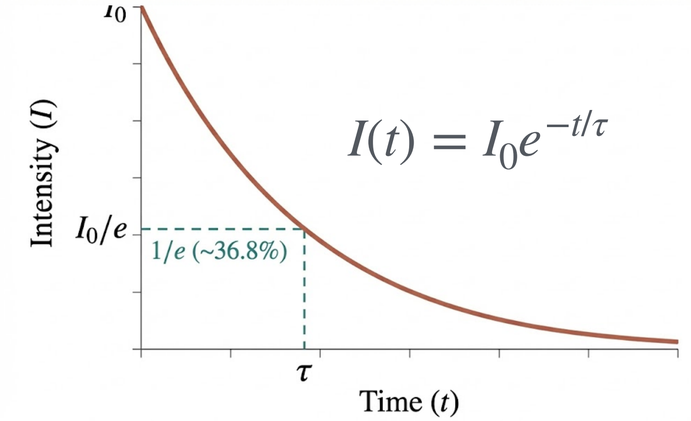


Hassan et al., "Anatomy-Specific Classification...", IEEE Trans. Biomed. Eng., 2023

Fluorescence Lifetime Imaging Microscopy (FLIM)

- FLIM measures how fast fluorescence decays after excitation
- Lifetime: average time in excited state
- Independent of fluorophore concentration or intensity



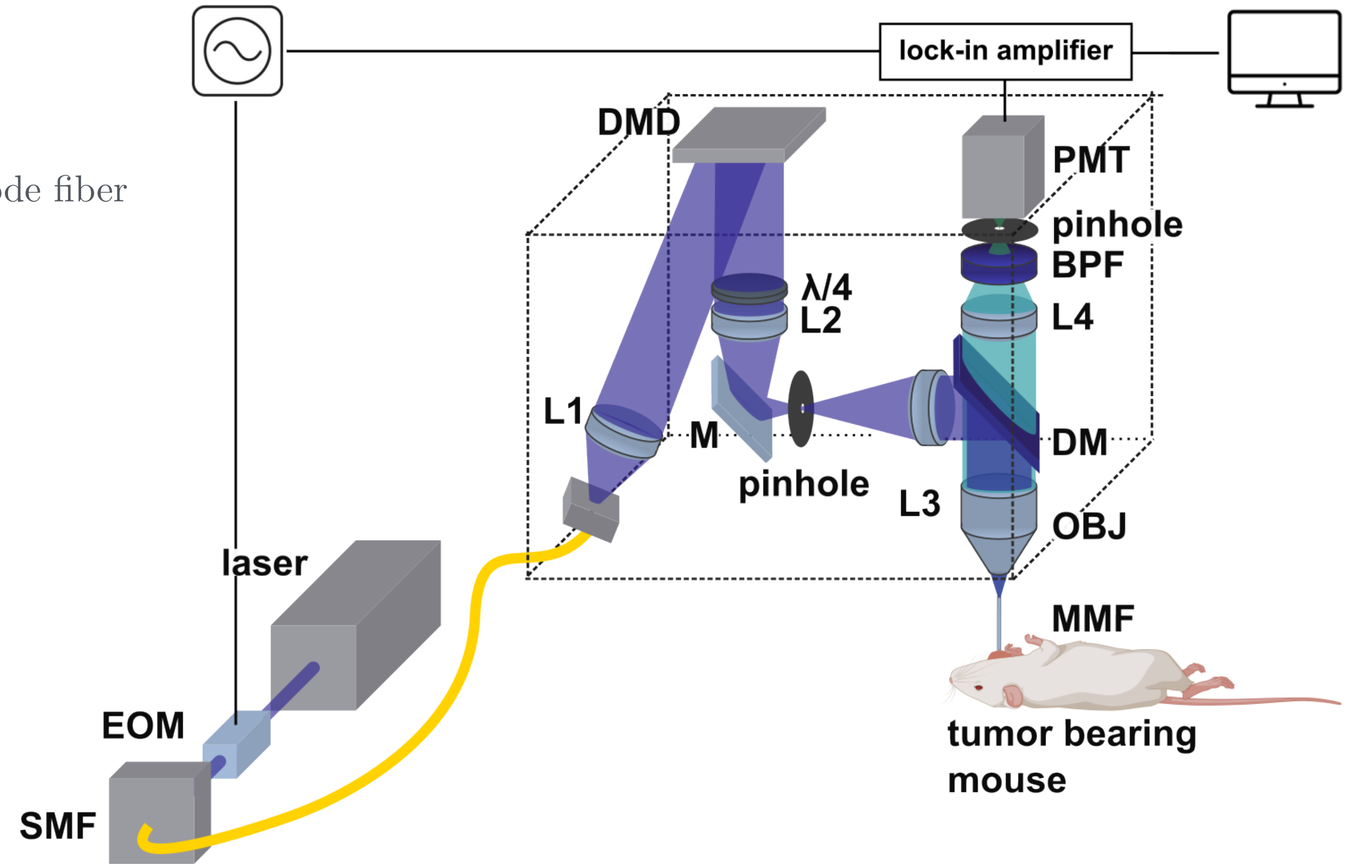


Gibson et al., 2011

System Overview: Frequency-Domain FLIM Endoscope

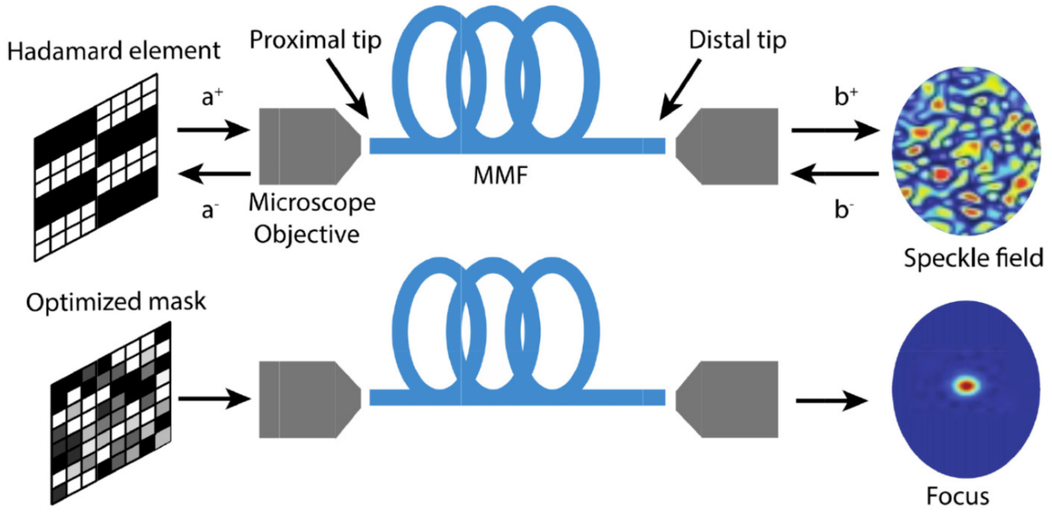
- 80 MHz modulated CW laser excites fluorophores
- DMD shapes the beam to focus through the multimode fiber
- Fluorescence collected back through same fiber
- PMT detects the modulated emission signal
- Lock-in amplifier extracts phase + demodulation

$$\tau = \frac{1}{2\pi f} \tan(\phi)$$



Focusing Through a Multimode Fiber

- MMFs scramble the input wavefront resulting in a speckle at output
- To focus, we measure the Transmission Matrix (TM)
- The TM maps DMD patterns (input modes) to output field
- By shaping the input phase, we generate a focus at the distal end

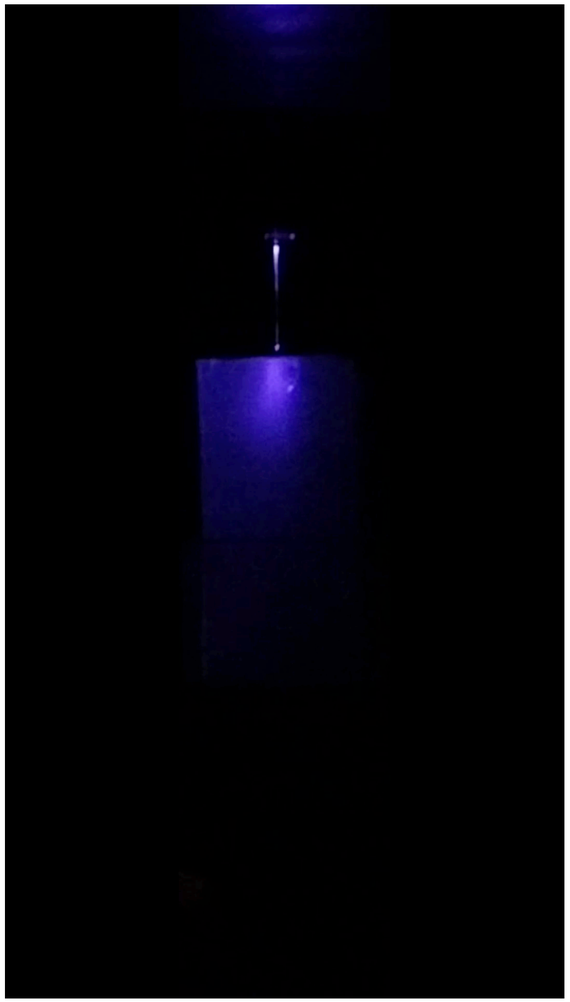


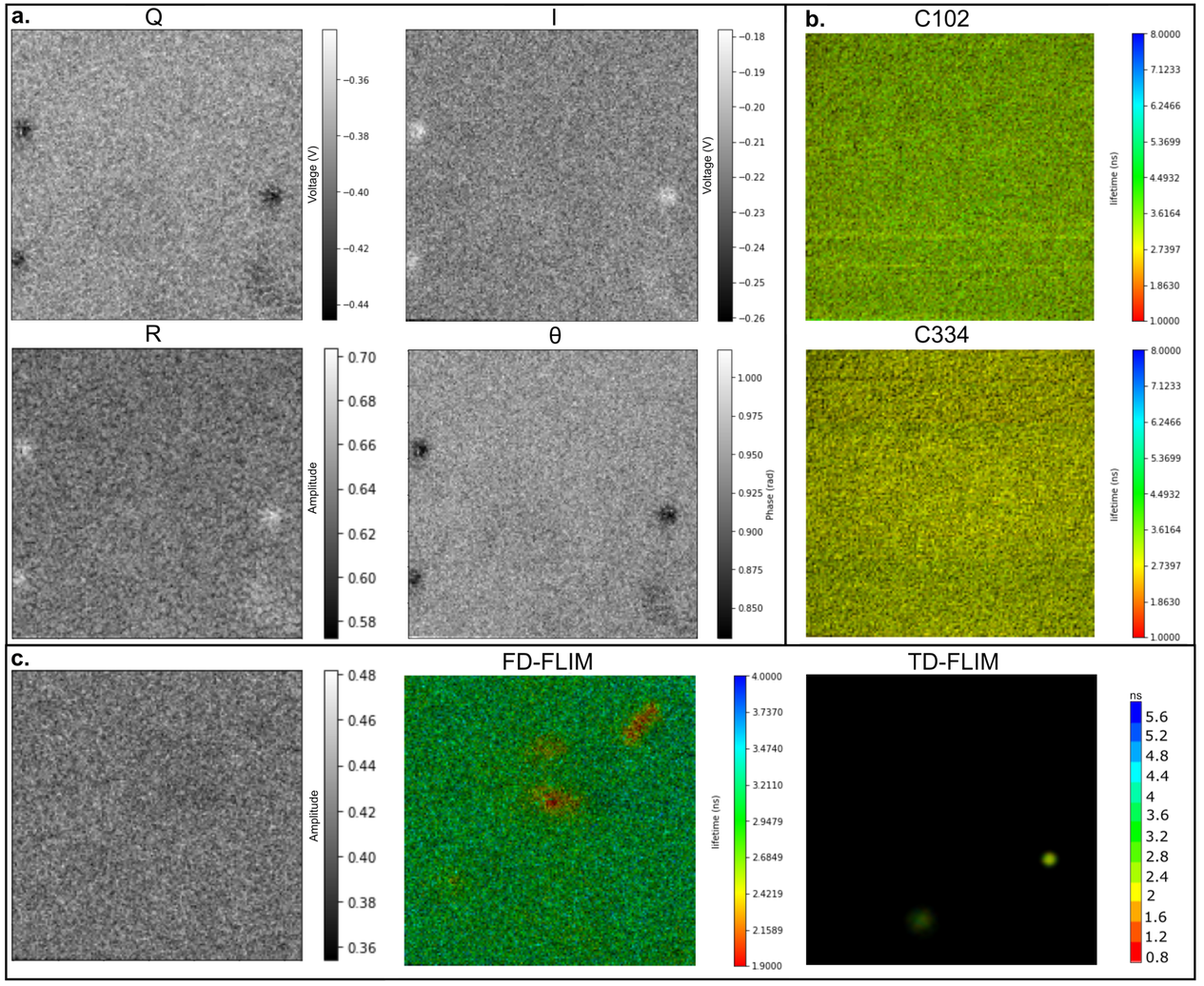
$$\mathbf{b} = \mathbf{T} \cdot \mathbf{a}$$

$$\mathbf{a}_{\text{opt}} \propto \mathbf{T}^{\dagger} \cdot \mathbf{b}_{\text{target}}$$

A. M. Caravaca-Aguirre and R. Piestun, "Single multimode fiber endoscope," Optics Express, vol. 25, p. 1656, Feb. 2017.

Imaging Workflow





Future Work

1. TM Stability & Imaging Robustness

- Quantify TM drift over time and under fiber bending.
- Evaluate lifetime measurement repeatability over several iterations.
- Develop real-time TM degradation monitoring via correlation metrics.

2. Adaptive Modal Excitation

- Systematically excite and image LP modes to identify robust mode families.
- Analyze how environmental perturbations affect image quality.
- Toward adaptive imaging systems that dynamically select stable modes for robust FLIM.