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# Endoscopic Photon Time-of-flight System for Monitoring Chemotherapy Response

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**Abstract:** We present a hybrid micro-camera time of flight endoscopy system to assess tumor response both superficially and deep below the mucosa layer. System design and preliminary results are presented. © 2024 The Author(s)

## 1. Introduction

Diffuse optical spectroscopy has been widely used to characterize tumors' biochemical composition and monitor therapeutic response in neoadjuvant chemotherapy patients [1-2]. In the context of esophageal and rectal cancers, chemotherapy can potentially disintegrate the malignant tumor into smaller clusters situated below the mucosa layer [3]. An ideal chemotherapy response evaluation tool therefore offers both high spatial resolution and depth sensitivity. Commonly employed methods encompass X-ray imaging and Optical Coherence Tomography (OCT). X-ray imaging offers poor resolution and exposes patients to harmful radiation. OCT, despite its superior resolution, suffers from limited depth sensitivity and high clinical cost. Time-domain diffuse optics spectroscopy can probe tens of millimeters in tissue and offers valuable insight on tissue composition, but it lacks spatial resolution. Imaging superficial layers together with depth-sensing capability could provide a holistic understanding of chemotherapy treatment response.

In this work, we propose a hybrid micro-camera photon Time-of-Flight spectroscopy (U-pTOF) endoscope system for the specular imaging and depth sensing of tissue. Endoscopy offers the advantage of providing direct and real-time visualization of internal structures as well as enabling biopsies. On the other hand, pTOF probes deep inside the surface by targeting the tumor's hemoglobin biomarkers such as H2O, Hb, HbO2, HbT and lipid.

## 2. Methods and Results

The layout of hybrid endoscopy is shown in Fig. 1. The side-viewing camera consists of an AMS NanEye (NEM RGB_2M_FOV120_F4.0) camera and a right-angle prism (Edmund Optics 2mm uncoated). The field-of-view of the camera is illuminated using a custom fiber-coupled light source based on 5 discrete wavelengths. The pTOF optical arrangement consists of a proximal-end broadband photon time-of-flight system. The system is powered by a supercontinuum laser source and motorized Pellin Broca prism, which enables wavelength selection [4]. The source and detector fibers are integrated into the hybrid probe by using right angle prism to illuminate and collect light sidewise. The U-pTOF probe diameter is 7 mm. A source detector distance of 1.5 cm is used to probe about a millimeters inside the tissue.

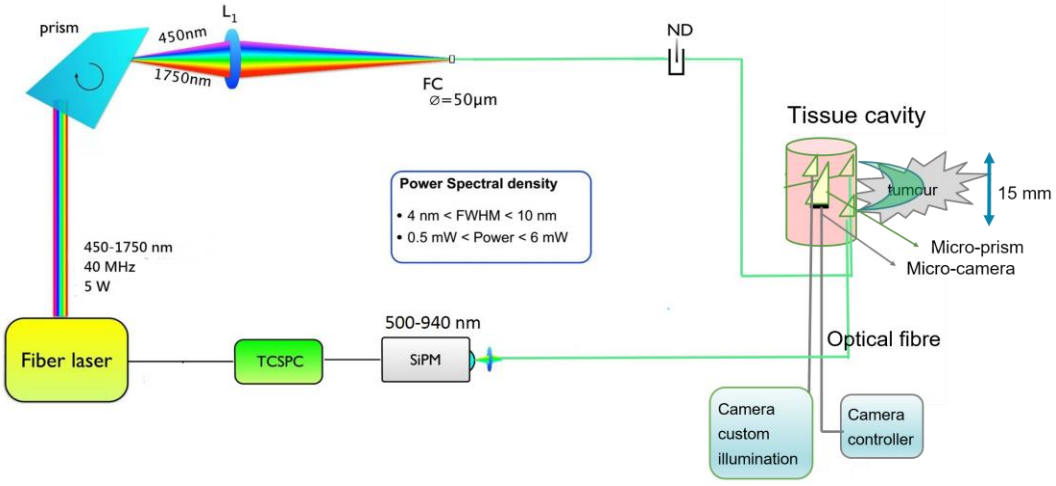


Fig. 1. Hybrid micro-camera photon Time-of-Flight spectroscopy (U-pTOF) experimental setup.

Fig. 2 shows the results from the imaging system with and without the prism, using a 1951 USAF resolution test chart and bovine tissue bought from store. The side-viewing camera suffers from significant distortion; however, we expect these results to improve through reducing the numerical aperture of micro-camera and by using image correction algorithms.

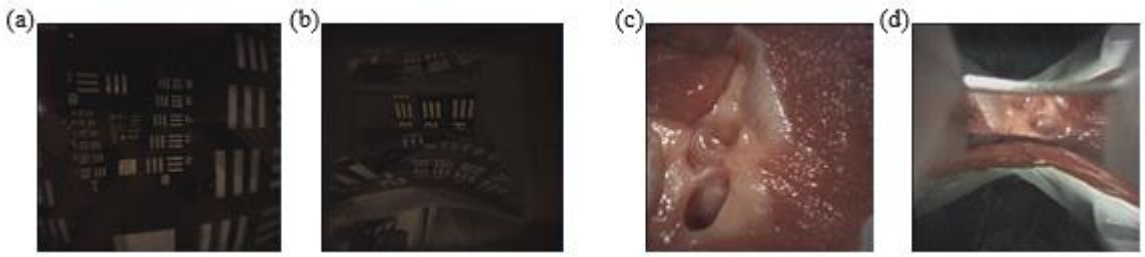


Fig. 2. Micro-camera image of (a) resolution target with a front-viewing camera (b) resolution target with a prism-mounted, side-viewing camera (c) bovine tissue with a front-viewing camera (d) bovine tissue with a prism-mounted, side-viewing camera.

The time-of-flight arm of the probe is validated using MEDPHOT protocol [5]. The half MEDPHOT matrix from BioPixS Ltd is used for this purpose. The linearity test results of the proximal time of flight system at 740 nm are shown in Fig. 3. As expected, the pTOF system shows linear behavior over the wide range of optical properties seen in MEDPHOT matrix. There is slight nonlinearity higher absorption values especially for high scattering C and D series phantoms.

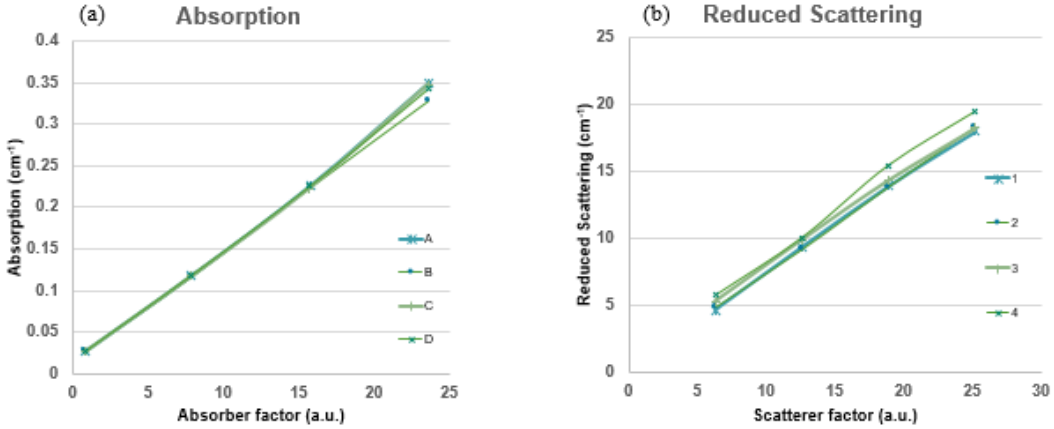


Fig. 3. Linearity response of the proximal end pTOF system (a) absorption linearity for 4 series (A, B, C, D) of MEDPHOT scattering values (b) scattering lineary for 4 series (1, 2, 3, 4) of MEDPHOT absorption values.

## Conclusion

We present a hybrid micro-camera time-of-flight system aimed at monitoring superficial and deep tissue response to chemotherapy. The optical characterization of the system shows promising results for clinical translation. The future work involves enrolling the system for esophageal and rectal cancers chemotherapy response monitoring.

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