Laboratory for Biomedical Imaging & Sensing

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TECHNION Israel Institute of Technology

OASIS 8

Homodyne Time-of-Flight Acousto-Optic Imaging for Low-Gain Photodetector

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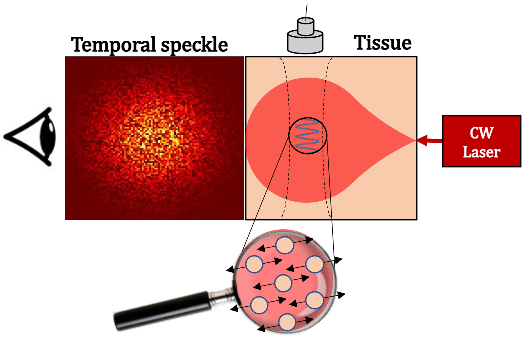
(1) Acousto Optic Imaging

Acousto optics imaging is a hybrid imaging method that measures light fluence rate inside tissues using ultrasound modulation of light.

In AOI, the tissue is both illuminated with a coherent laser and insonified with an ultrasound transducer, leading to a pressure-induced refractive-index modulation and vibrations of the optical scatterers in the insonified regions.

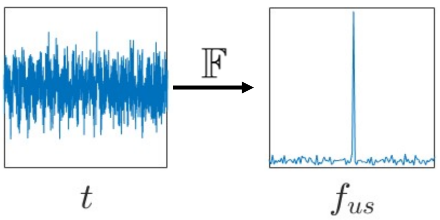
Photons that travel through the insonified region experiences a phase modulation with the same frequency as that of the ultrasound wave, manifested as a temporal modulation of the speckle grains intensity formed on the boundary proportional to the fluence rate in the insonified region.



Utilizing time-of-flight (ToF) principle to reconstruct entire line with single US pulse.

(2) Light Detection Schemes

Using high-bandwidth photodetectors to produce time-domain signals, faster than the US frequency and speckle decorrelation.



Main Challenge:

$$SNR \propto \sqrt{\#Detectors}$$

Check our paper!
Levi, A.R. et al. Biomed. Eng. Lett. (2022).

(3) Optical Signal

N speckle grains

$$I_{bkg} \gg I_{AO}$$

Random phase $U \sim [0, 2\pi]$ I.I.D.

$$I_D = \sum_i^N I_{bkg,i} + 2\sum_i^N \sqrt{I_{bkg,i} I_{AO,i}} \cos(2\pi f_{US} t + \phi_i)$$

$$Noise = \sqrt{N \cdot E[I_{bkg,i}]} \qquad Signal = \sqrt{N \cdot E[I_{bkg,i} I_{AO,i}]}$$

$$SNR_{AO} = \frac{Signal}{Noise} = \sqrt{I_{AO}}$$

Independent with the unmodulated intensity | Signal **amplified** by unmodulated light

Artificially injects more background light and amplify the signal without changing the SNR.

(4) SNR in AOI Detection

Low intensity of reemitted light and limited number of detectors require high gain photodetector as PMT.

$$SNR_{PMT} = \sqrt{\frac{N \cdot Q}{2B \cdot F}}$$

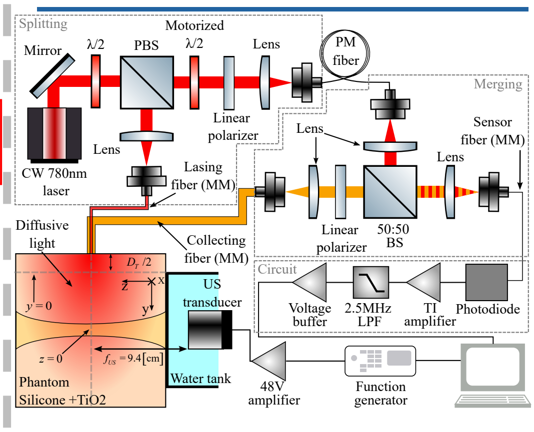
Low QE | **Noise Figure** | **Not Scalable**

$Q_{PMT} = 5\%$ $F_{PMT} = 1.4$

Replace PMT with low-gain photodetector with better characteristics → **Higher SNR**

$$Q_{PD} = 76\% \rightarrow G_{SNR} = 4.5$$

(5) System Setup

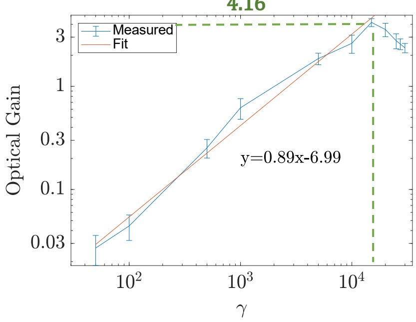


(6) Optimal Optical Gain

In strong reference intensities, the dominant noise is the optical shot-noise → the photodiode-based scheme introduced better SNR.

Optimal SNR Gain: 4.16

$$\gamma = \sqrt{\frac{I_{ref}}{I_{bkg}}}$$



Optimal Reference intensity factor: 1.5e4

(7) Results