Developing a stochastic model for acousto-optic tissue modulation
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Problem to be solved

And acousto-optics
Combining photoacoustics
To estimate $V$
This efficiency depends on the coupling of light and sound by the medium.

Where:

$P_{0} = \mu_{0}\Phi$

The generated photoacoustic pressure depends on the absorption coefficient and local fluence.

Where:

$P_{0}$ is the initial US pressure after the laser pulse, $\mu_{0}$ the absorption coefficient and $\Phi$ the fluence.

Acousto-optics

1. Illumination by long coherence length laser
2. Tagging of light by ultrasound
3. Detection of tagged photons: Speckle contrast, Fabry-Perot interferometer, holography, spectral hole burning etc.

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Where:

$P_{T, 2}$ is the normalized tagged power, $P_{T, 1}$ probability for photon to go from $n$ to $m$ and $P_{T, 2}$ the probability to tag in tagging region at position 2.

Combining photoacoustics and acousto-optics

When photoacoustics and acousto-optics are combined the fluence distribution cancels out. We need one acousto-optic measurement and one photoacoustic measurement in transmission mode. In reflection mode we only need one acousto-optic and one photoacoustic measurement.

$$P_{n, 2} = \frac{A_{n, 2} \Omega_{n} A_{T, 2} E_{n, 1, 2} E_{n, 2, 3}}{4\pi P_{T, 3}^{2} V_{L}^{2}}$$

Where: $\mu_{n, 2}$ absorption coefficient at 2, Detector aperture area $A_{n}$ and opening angle $\Omega_{n}$, $A_{T, 2}$ the average frontal area of tagging zone and $V_{L}$ the volume of the tagging zone.

Problem to be solved

$V_{L}$ and $A_{T, 2}$ are unknown and related to the tagging efficiency.

This efficiency depends on the coupling of light and sound by the medium. To estimate $V_{L}$ and $A_{T, 2}$ the interaction must be modeled.

Stochastic AO model

Pressure Tagging

Light scattering particles oscillate due to the acoustic pressure (1)

Refractive index variations due to acoustic pressure (2)

Phase change for refractive index modulation in single voxel:

Where $\Delta n(t)$ is the refractive index variation, $\lambda$, the optical wavelength, $X(t)$ the particle displacement and $DV$ the voxel volume.

Each voxel is a source of tagged photons. A small fraction of incoming light is tagged. The probability for a photon to be tagged in a voxel is given by this fraction:

$$\varphi_{n}(t) = X(t) (\sin(\alpha) + \sin(\beta)) \frac{2\pi}{\lambda}$$

$Pr_{\text{tag}(r)}(r)$ over all space $S$ we obtain the total probability of tagging in space $S$.

$$P_{T, 2} = 1 - \exp\left(-\int_{S} Pr_{\text{tag}(r)}(r) \frac{\Delta V}{\Delta V} \right)$$

Where $Pr_{\text{tag}(r)}(r)$ over all space $S$ we obtain the effective tagging volume $V_{0}$

$$V_{0} = \int_{S} Pr_{\text{tag}(r)}(r) \frac{\Delta V}{\Delta V}$$

This expression takes us one step closer to quantized measurements on $\mu_{n, 2}$.

Outlook

- Calculate $A_{T}$ using $V_{l}$ and shape of the tagging volume.
- Investigate probability of untagging photons and the influence of photon paths.
- Validation of the model using Monte-Carlo simulations.