

# Ultrasound Assisted Optical Tomography: A Modality for High Resolution Imaging

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# Near-Infrared Spectroscopic Imaging

- The absorption coefficient spectrum in the near-infrared region extracted from soft tissue organs has important diagnostic application
- The spectral information can be translated to functional parameters such as Hb concentration and oxygen partial pressure
- This is done in diffuse optical tomography (DOT)

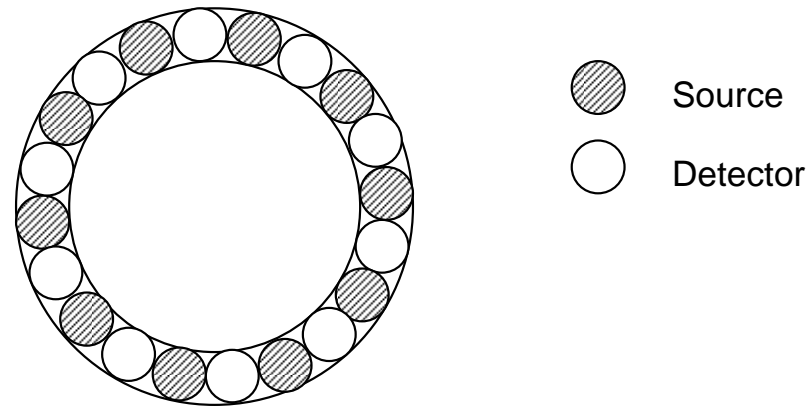
# Limitations of DOT

- The major limitation is the poor spatial resolution owing to the diffuse propagation of light in tissue
- Consequently, cell (or molecular) level imaging with DOT is currently not possible
- Light has limited depth of penetration

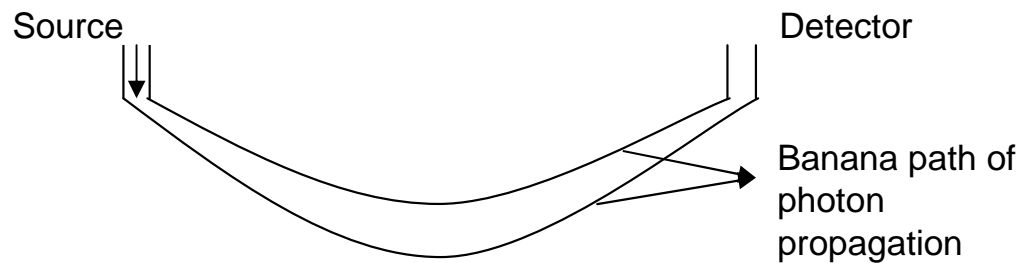
# Imaging with U/S Tagged Photons

- U/S can be focused to a narrow region of interest (ROI) in tissue. Light interacting with U/S gets frequency-shifted. The frequency-shifted light carries information on the tissue optical properties corresponding to the ROI
- In U/S assisted DOT, average properties of the ROI can be extracted from the frequency-shifted light measured on the boundary

# Tomographic Imaging of the ROI

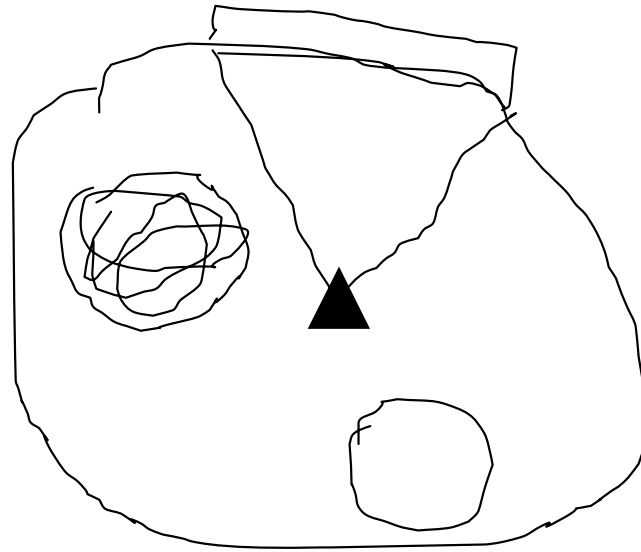


(a)



(b)

Fig. 1. Schematic of the source-detector assembly: The diffused light paths cross from all the sources in the middle region (1(b))



# Tomographic Imaging of the ROI

- The insonified ROI is illuminated from various directions
- The U/S exerts a force (which can be quantitatively estimated from the U/S transducer) which sets the tissue particles in vibration. In order to excite the shear mode, the frequency of forcing is kept low.
- Solution of the force balance equation corresponding to the ROI yields the spatial distribution as well as the temporal evolution of the tissue displacement

# Light Interaction with the ROI

- We propagate photons through the tissue using Monte Carlo simulation. Both photon weights and travel time are tracked in the simulation.
- This allows us to compute the amplitude (and intensity) autocorrelation of the photons received at a boundary detector
- Owing to the vibration of the tissue particles in the ROI, the autocorrelation contains a modulation

# Light Interaction with the ROI

- The depth of modulation is affected by the optical properties ( $\mu_a$  and  $\mu_s$ ) and the amplitude of vibration of the tissue particles
- The latter dependence helps us compute the elastic properties of the ROI
- Approximate expressions connecting the modulation depth and the optical and elastic properties of the ROI are available

# Light Interaction with the ROI

- Inverting this expression, the average properties of the ROI can be recovered from the boundary measurements of the modulation depth.

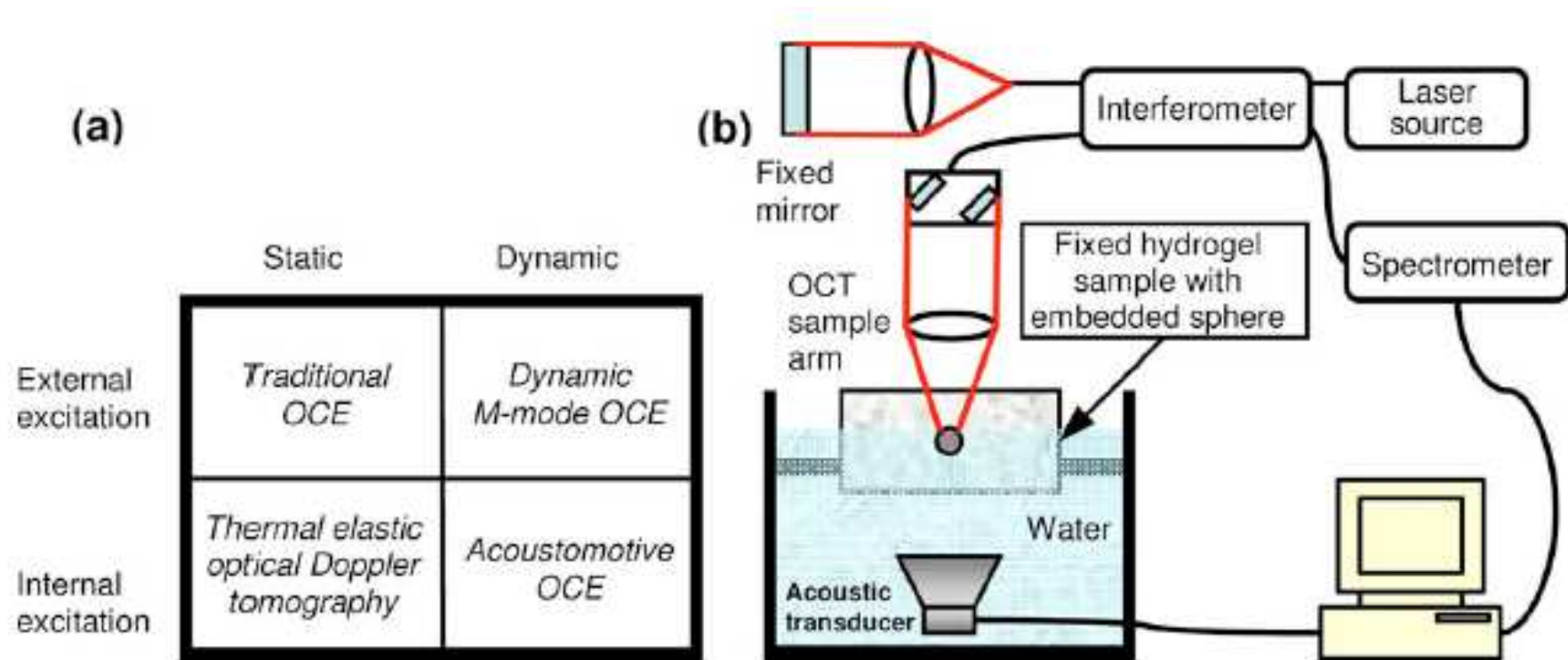
# Tomography of the ROI

- The continuous distribution of properties over the ROI is discretized through a set of nodes, consistent with an FEM discretization.
- The nodal unknowns thus approximately determine the targeted distribution (of the optical and mechanical properties)
- We aim to do a tomographic recovery of these properties from a set of measurements, corresponding to different angles of illumination and input frequencies of the U/S force

# Reconstruction

- We set up the perturbation equations connecting the tissue property updates to the changes in the modulation depth
- These perturbation equations are solved using a regularized Newton-like algorithm, which would reconstruct the spatially resolved property distribution in the ROI
- The resolution is limited only by the scattering mean free path

# Verification through Optical Coherence Tomography



# Temperature Control in Hyperthermia Treatment

- Aim: To control the power and delivery sequence of pulses from a laser so that tumor regions are kept at an elevated temperature during the radiation therapy.
- The absorption can be enhanced by injecting gold nanoparticles which stick to the tumor.

# Preliminary Experiments

- Through a photo-acoustic tomography (PAT) experiment, locate the tumors and assess their  $\mu_a$
- Locate the fiber delivery systems on the boundary closest to the tumor
- From  $q_0(r-r_i)$ , the strength of the light pulse at  $r = r_i$ , find the energy absorbed at the absorption inhomogeneity as  $H_i = \Phi(r)\mu_i(r)$ . From  $H_i$ , the heat input  $Q_i$  can be computed.

# Temperature Control

- From PAT pressure measurement on the boundary,  $p_0$  at the tumor can be computed. Changes in  $p_0$  at the source can be used to keep track of the changes in temperature at the tumor.
- The temperature  $T$  at the tumor obeys the following equation:

# Temperature Control

$$\rho C \frac{\partial T}{\partial t} = \nabla \cdot (K \nabla T) - W_b C_b (T - T_a) + Q$$

$\rho$ : *tissue density*

$C$ : *tissue specific heat*

$T$ : *temperature*

$K$ : *tissue thermal conductivity*

$W_b$ : *blood perfusion rate*

$C_b$ : *specific heat of blood*

$T_a$ : *arterial blood temperature*

$Q$ : *power applied via laser*

$$\nabla_k \nabla \phi - \mu_a \phi = \frac{g}{\omega} (v - v_0)$$

$$\left( \nabla^2 - \frac{1}{c^2} \right) \psi(r, t) = S$$

# Temperature Control

- Discretized state space model for the above equation is:

$$\dot{x} = A(x - x_0) + Bu$$

A is an  $n \times n$  system response matrix incorporating both conduction and perfusion terms

B is an  $n \times m$  system input matrix ( $m$  is the no of points on the boundary from where light is delivered)

$u$  defines the power delivered from each of the light sources

# Temperature Control

- For simplicity, we assume that heat conduction between tumors is negligible, implying that  $A = \alpha I$ .
- This leads to a steady state solution

$$x = (sI - \alpha I)^{-1}Bu$$