School of Engineering

A novel phased-array approach to diffuse optical imaging

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Introduction

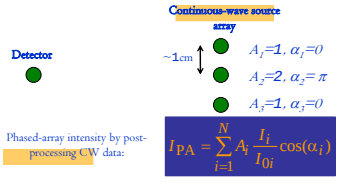
Diffuse optical imaging is a noninvasive technique that finds applications in the study of highly scattering media.

One important example is near-infrared imaging of biological tissue in areas such as functional mapping to identify regions of brain activation[1] and optically differentiate breast cancer through determination of tissue parameters such as the oxygenation and the concentrations of hemoglobin, lipid, and water in breast tissue.[2]

However, NIR diffusive light imaging suffers from relatively low spatial resolution and poor depth discrimination due to the diffusive nature of light propagation.

Three-element phased-array approach

Our multi-source (multi-detector) phased-array approach enhances spatial resolution and achieves depth discrimination. [3,4]



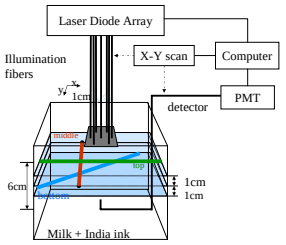
Phased-array intensity by post-processing CW data:

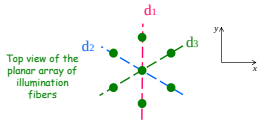
$$I_{PA} = \sum_{i=1}^{N} A_i \frac{I_i}{I_{0i}} \cos(\alpha_i)$$

- A_i : introduced amplitude factors for source array
- α_i : introduced phase factors for source array
- I_i: measured intensity
- I_{0i} : background intensity
- N : number of sources (3 in this case)

Experimental setup

Three three-element phased-array are used to study a turbid medium with three black cylinders embed in it at different depth.

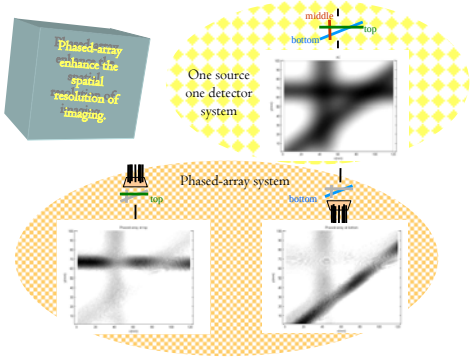




Maximum of the phased-array intensities along the three directions:

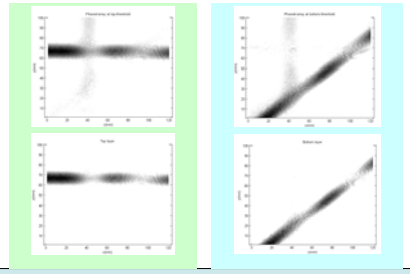
$$I_{PA} = \max\left(I_{PA}^{(d_1)}, I_{PA}^{(d_2)}, I_{PA}^{(d_3)}\right)$$

$$I_{PA}^{(d1)} = \frac{I_{up}^{(d1)}}{I_{0\text{-}up}^{(d1)}} + \frac{I_{down}^{(d1)}}{I_{0\text{-}down}^{(d1)}} - 2\frac{I_{center}^{(d1)}}{I_{0\text{-}center}^{(d1)}}$$

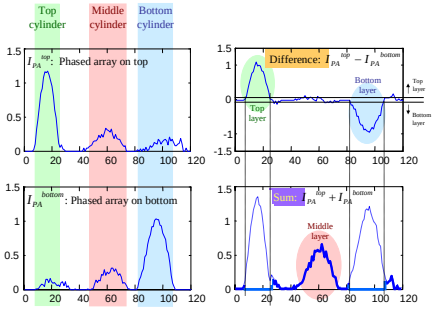


Approach to depth discrimination

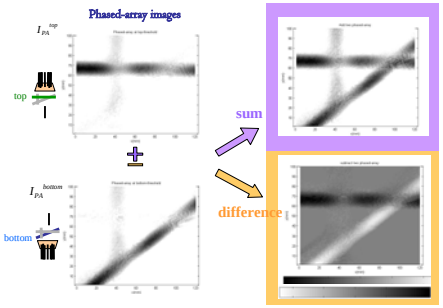
- First step: Set the threshold to get the top and bottom layers.



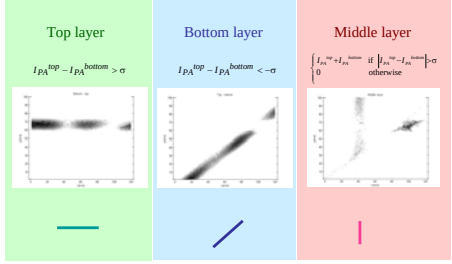
- Second step: separate the middle layer. (principle)



- Second step: separate the middle layer. (processing)



Depth-resolved images



Phased-array compare with second-derivative

Three-element phased-array approach is conceptually similar to a discrete spatial second-derivative of the intensity for a single source-detector system:

- **Discrete second-derivative**

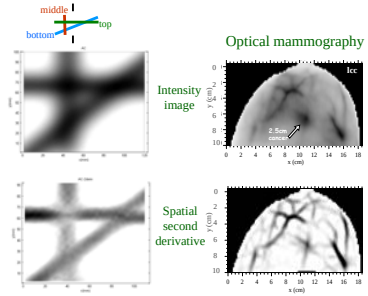
$$\frac{I_2''(x)}{I_{02}} = \frac{\frac{I_1(x-\Delta x)}{I_{01}} - 2\frac{I_2(x)}{I_{02}} + \frac{I_3(x+\Delta x)}{I_{03}}}{(\Delta x)^2}$$

But the 2nd-derivative imaging can not give you depth discrimination.

- **Three-element phased array**

$$I_{PA} = \sum_{i=1}^{3} A_i \frac{I_i}{I_{0i}} \cos(\alpha_i)$$
$$= 1 \cdot \frac{I_1}{I_{01}}\cos(\pi) + 2 \cdot \frac{I_2}{I_{02}}\cos(0) + 1 \cdot \frac{I_3}{I_{03}}\cos(\pi)$$
$$= (-1) \cdot \frac{I_1}{I_{01}} + 2 \cdot \frac{I_2}{I_{02}} + (-1) \cdot \frac{I_3}{I_{03}}$$

An example of 2nd – derivative method used in optical mammography[5]



Conclusions

We have presented a multi-source phased-array approach to improve the spatial resolution and achieve depth discrimination in diffuse optical imaging:

- use an array of continuous wave (CW) light sources and perform data post-processing by introducing amplitude and phase factors
- selectively enhance the spatial resolution over different depths within the sampled volume.
- Depth discrimination because of a variable sensitivity as a function of depth

References

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Acknowledgements

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