Optical Mammography for tumor detection and oximetry

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Abstract: Optical mammography uses visible and near-infrared light to detect breast cancer. We present second-derivative images and oxygenation index images that enhance the spatial resolution and help discriminate benign and malignant lesions on the basis of their oxygenation level. We also present a novel multi-element phased-array approach which can provide depth discrimination capabilities. Such enhanced spatial and functional information can help develop optical mammography into a clinically useful imaging modality for detection and monitoring of breast cancer.

Introduction

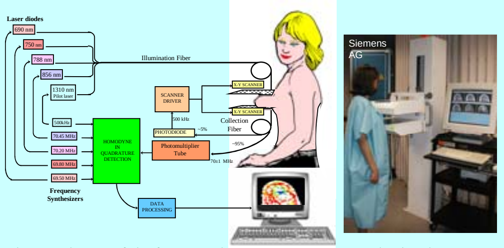
Some of the reasons that account for the potential of optical mammography are its non-invasiveness, safety, relatively compact instrumentation (suitable for doctor's office use, bed-side use, and even home use), and cost-effectiveness.

Following the demonstration of the limited clinical value of diaphanography and lightscanning (the original optical breast imaging approaches) in 1990 [1], optical mammography has been significantly revisited. Rigorous models of light propagation in breast tissue [2], and time-resolved instrumentation [3,4,5] were developed. A more systematic study of the source of optical contrast featured by tumors [6,7] and the potential of combining optical imaging with magnetic resonance imaging [8], ultrasound imaging [9], x-ray imaging [10], and extrinsic contrast agents [11] were also explored.

Here, we present our results in the area of frequency-domain optical mammography aimed at enhancing the spatial and functional information content of optical mammograms.

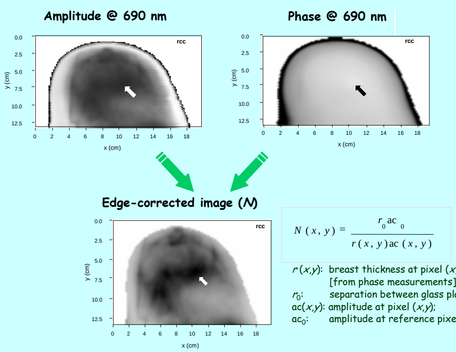
I. Instrumentation, and correction for edge-effects (N-images)

Frequency-domain instrument for optical mammography



Schematic diagram of the frequency-domain research prototype developed by Siemens Medical Engineering, Erlangen, Germany, for optical mammography [12]. The instrument consists of four laser diodes emitting at 690, 750, 788, and 856 nm, respectively, which are intensity-modulated at a frequency of ~70 MHz. The illumination and collection optical fibers are located on opposite sides of the breast, which is slightly compressed between two parallel glass plates. The optical fibers are scanned in tandem across the breast to yield two-dimensional projection images of the phase and amplitude of the intensity-modulated light. Two projections of each breast are typically acquired: craniocaudal (the geometry illustrated in the above figure) and oblique, obtained by rotating the glass plates by 45 degrees.

Using the phase to correct for the edge effects: the *N*-parameter

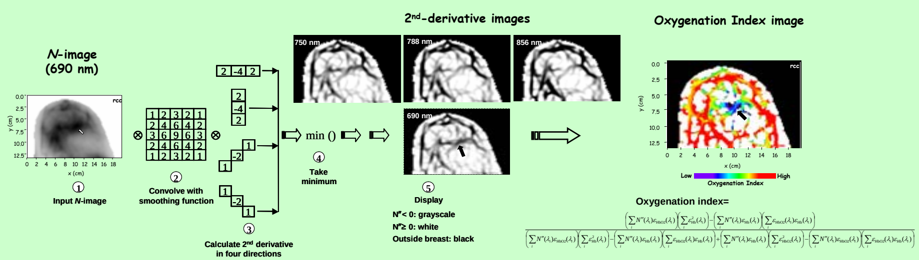


$$N(x,y) = \frac{r_0 \, ac_0}{r(x,y)\, ac(x,y)}$$

- $r(x,y)$: breast thickness at pixel (x,y) [from phase measurements];
- r_0: separation between glass plates;
- $ac(x,y)$: amplitude at pixel (x,y);
- ac_0: amplitude at reference pixel.

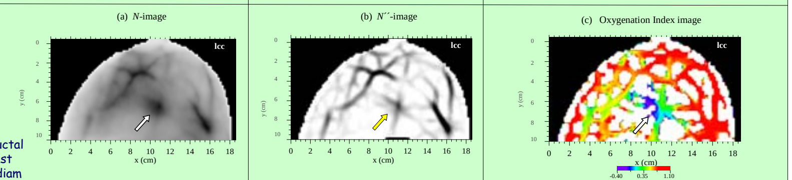
The amplitude and phase images at each wavelength are combined into edge-corrected (*N*) images that improve the detectability of tumors. This correction of edge effects (which are mostly due to boundary effects and reduced tissue thickness by the breast edge) is based on a normalization of the amplitude according to the tissue thickness estimated with the phase data [13].

II. 2nd-derivative [14] and Oxygenation-Index image [15] processing

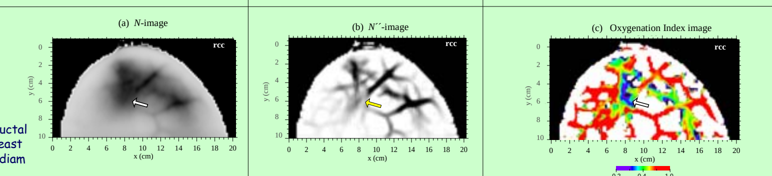


N-images (690 nm)	2nd-derivative images (690 nm)	Oxygenation Index images

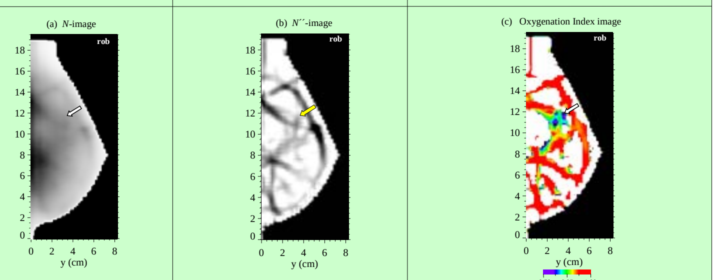
Patient No.: 311
Age: 82 y
Diagnosis: Invasive ductal carcinoma in left breast
Cancer size: 2.5-cm-diam



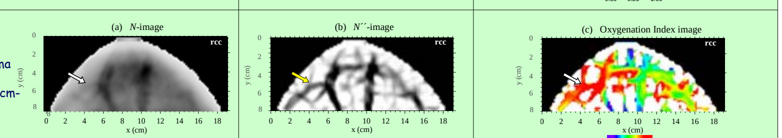
Patient No.: 233
Age: 67 y
Diagnosis: Invasive ductal carcinoma in right breast
Cancer size: 3.0-cm-diam



Patient No.: 258
Age: 47 y
Diagnosis: Invasive ductal carcinoma in right breast
Cancer size: <0.5-cm-diam

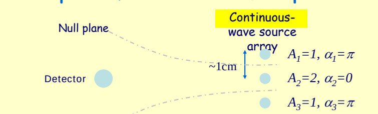


Patient No.: 195
Age: 51 y
Diagnosis: Fibroadenoma in right breast
Cancer size: 2.0-×1.5-cm-diam



III. Phased-array approach

Description of our three-element phased-array approach [16]



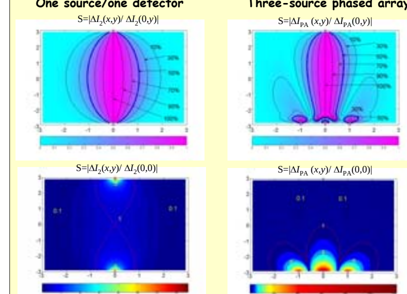
Phased-array intensity by post-processing CW data:

$$I_{\text{P-A}} = \sum_{i=1}^{3} A_i \frac{I_i}{I_{0i}} \cos(\alpha_i)$$

- A_i: introduced amplitude factors for source array
- α_i: introduced phase factors for source array
- I_i: measured intensity of the i-th source
- I_{0i}: background intensity of the i-th source

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

Spatial distribution of sensitivity functions [16,17]

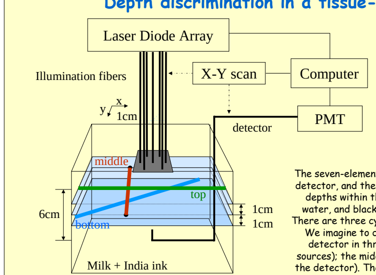


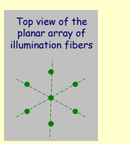
The region of sensitivity of the phased-array intensity is narrower than that of the single-source intensity, suggesting an improvement in spatial resolution.

The non-symmetric distribution of the phased-array sensitivity function implies a much higher contrast close to the source array than to the detector.

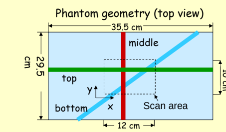
Our phased-array approach can <u>improve the spatial resolution</u> and <u>depth discrimination</u> in diffuse optical imaging.

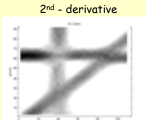
Depth discrimination in a tissue-like phantom [17]

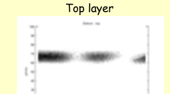


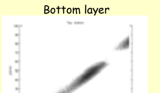


The seven-element, 2-dimensional source array, the single detector, and the three cylinders embedded at different depths within the highly scattering medium (2% milk, water, and black India ink). PMT: photomultiplier tube. There are three cylinders at different depths along z axis. We imagine to divide the medium between source and detector in three layers: the top layer (close to the sources); the middle layer and the bottom layer (close to the detector). The scan began from the left lower corner in top view.









Conclusions

- **2nd-derivative optical images provide enhanced spatial information for:**
  - Detection of breast lesions and vasculature;
  - Identification of regions of interest to be further analyzed to assess their oxygenation.
- **Oxygenation images can help discriminate benign and malignant lesions on the basis of their oxygenation level.**
- **The phased-array approach enhances spatial resolution similarly to the spatial second-derivative and provides depth information.**
- **Combining enhanced spatial and functional information into optical mammograms may improve the sensitivity and specificity of this imaging modality**

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