Parallel Scanning Architecture for Mammogram-Based Diffuse Optical Imaging

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1 Background

In this brief paper, we demonstrate a working prototype of an optical breast imaging system using parallel-paddle architecture with dual-direction scanning, of which the designed module is incorporated with a mammographic system for the acquisition of optical information in both the up-down and down-up directions. This device is handled through compressing breast tissue with using two parallel paddles. Compared with the single-direction projection scheme, double optical information can be acquired by dual-direction projection as using two pairs of 1-D scanning array with up-down and down-up projection, respectively. Additionally, the scanning module enables to move with a designated pitch to accommodate breast size for acquiring adequate data to reconstruct optical-property images. Currently, the continuous wave (CW) system operating at direct current (DC) light source of a single wavelength is convenient for breast screening instead of diagnosis.

Based on our previous results in the laboratory [1,2], this performed pilot study is validated by accompanied mammograms. The applications to imaging healthy and malignant breasts in a clinical environment show promising outcomes for the conducted mammogram-based diffuse optical imaging (DOI).

2 Methods

In the design using slab-type scanning [3,4], the quality of reconstructed images was restricted by the available data obtained from single direction projection. In this study, a dual-direction projection scheme was employed to design a scanning module with two sets of one dimensional scanning array of 7 by 7 source-and-detector pairs, which are mounted on the upper and lower compression plates. As shown in Fig. 1, ‘S’ and ‘D’ denote source array and detection array, respectively. Through this design, double NIR data can be acquired and better reconstructed optical-property images are expected. In our dual-direction scanning scheme, the transmitted optical information was acquired at the same cross section. In order to obtain such information at the same slice, the top and bottom scanning slabs concurrently shifted a span of S-D distance (in the Y direction), as shown in the left-most of Fig. 2. Figures 2(*a*) and 2(*b*) illustrates top-to-down and down-to-top optical paths for measurement, and it shows the procedure called a dual-direction scanning scheme. Moreover, the two scanning slabs enable to shift a half span of two source (or detector) channels in the X direction for the accommodation of acquiring optical data from a smaller breast, or just for obtaining more data to reconstruct images.

Figure 3(*a*) displays a phtograph of the system in the clinical environment, shown with a close-up view of the scanning module and optical probes (Fig. 3(*b*)). This imaging system was developed with using CW DC-type NIR light source. The mammogram in the cranio-caudal (CC) view was refered and adopted as prior structural information to decide NIR scanning sections. Currently, the system deploys a laser module (LDCU5/8202, Power Technology) with 830 nm (5 mW), of which the NIR light is directed into an optical switch (FOSW-1-16 -N-62-L-2, Enaco) with a 1 by 16 optical fiber bundle. The 17 fibers of the bundle have pure silica core (62.5 m) with silicone clad, suitable for the transmission of light with wavelengths from 700 nm to 900 nm, and each fiber has a diameter of 1.2 mm. The NIR source light is delivered to the central fiber in the bundle, and the remaining 14 input fibers surrounding the source fiber are connected to the source ends of scanning arrays with a collimator (10 mm in diameter) for each input fiber on the top and bottom slabs made of AL6061 alloy. Each of the slabs mounted over the compression paddle with a 2-mm gap moves and scans for a designated section of phantom/breast. The fiber bundle is 1 m in length and extends from the instrument cart to the phantom/tissue interface. The light transmission efficiency of the optical switch reaches around 83%, yielding an average source power of 4 mW at the phantom/tissue surface.

Subsequently, the acquired NIR data are used to reconstruct the optical-property images of tissue through inverse computation. The image reconstruction algorithm of DOI based on the diffusion equation involves both the forward computation and the regularization of inverse reconstruction [5–7]. The diffusion equation below

$$\nabla \cdot D\nabla\Phi(r) - \left(\mu_a - \frac{i\omega}{c}\right)\Phi(r) = -S_o(r), \qquad (1)$$

is to describe light transportation in a highly scattering medium such as breast tissue [3], where Φ is intensity, μ_a is the absorption coefficient in mm^{-1}, c is speed of light in the medium and D is the diffusion coefficient in mm.

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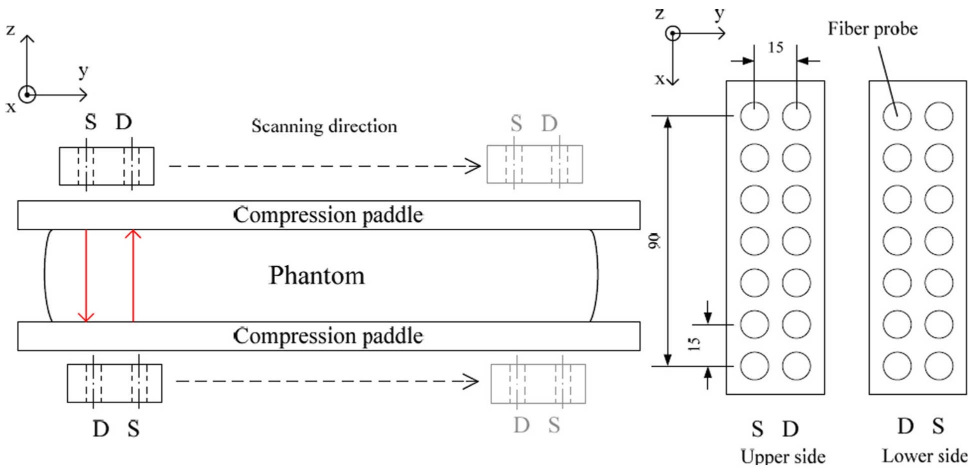

Fig. 1 Dual-direction projection scanning scheme

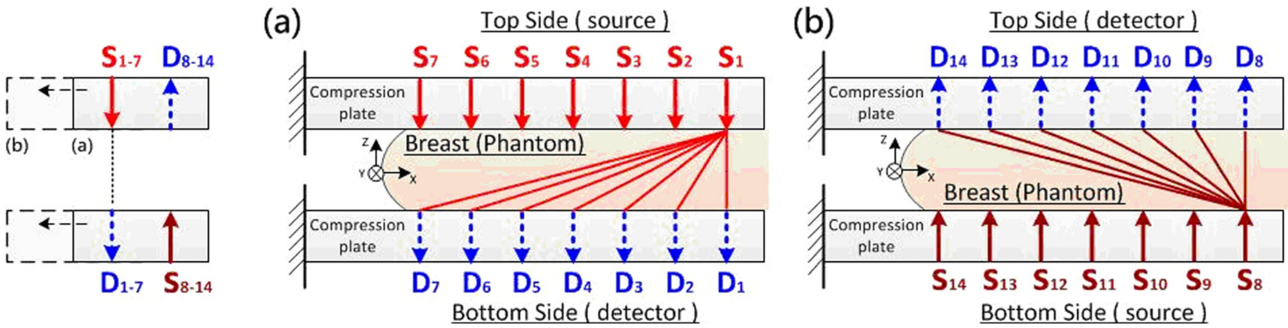

Fig. 2 Illustration of dual-direction projection scheme with transmission information (*a*) from top to bottom (7 × 7: S_1-$D_{1\text{-}7}$, S_2-$D_{1\text{-}7}$,. and S_7-$D_{1\text{-}7}$), and (*b*) from bottom to top (7 × 7: S_8-$D_{8\text{-}14}$, S_9-$D_{8\text{-}14}$,. and S_{14}-$D_{8\text{-}14}$)

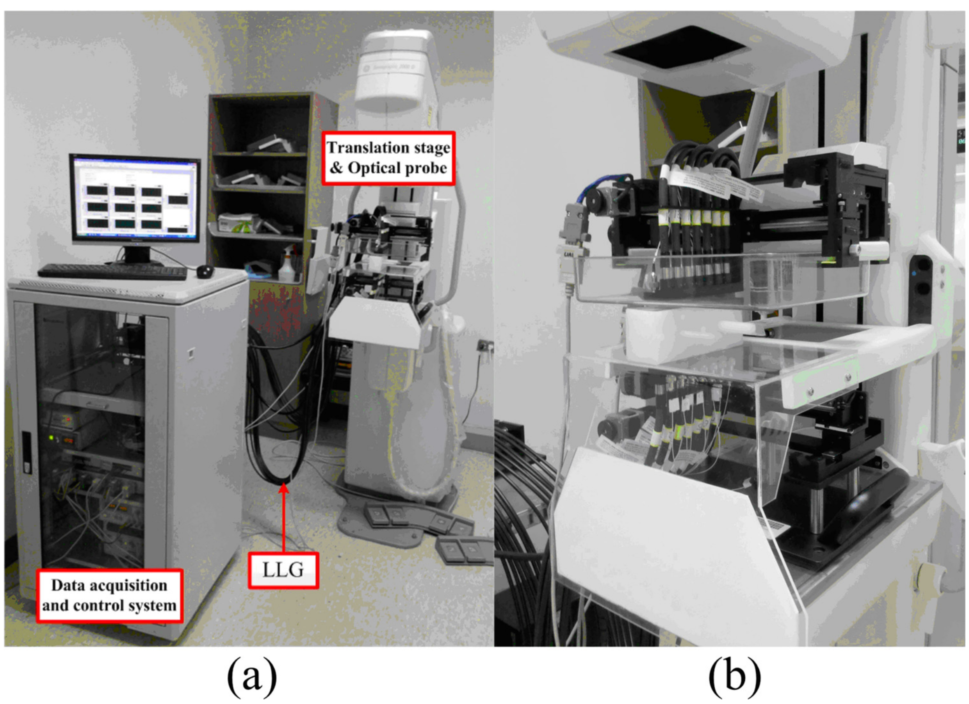

Fig. 3 (*a*) The self-developed system in the clinical environment and (*b*) a close-up view of the measuring device

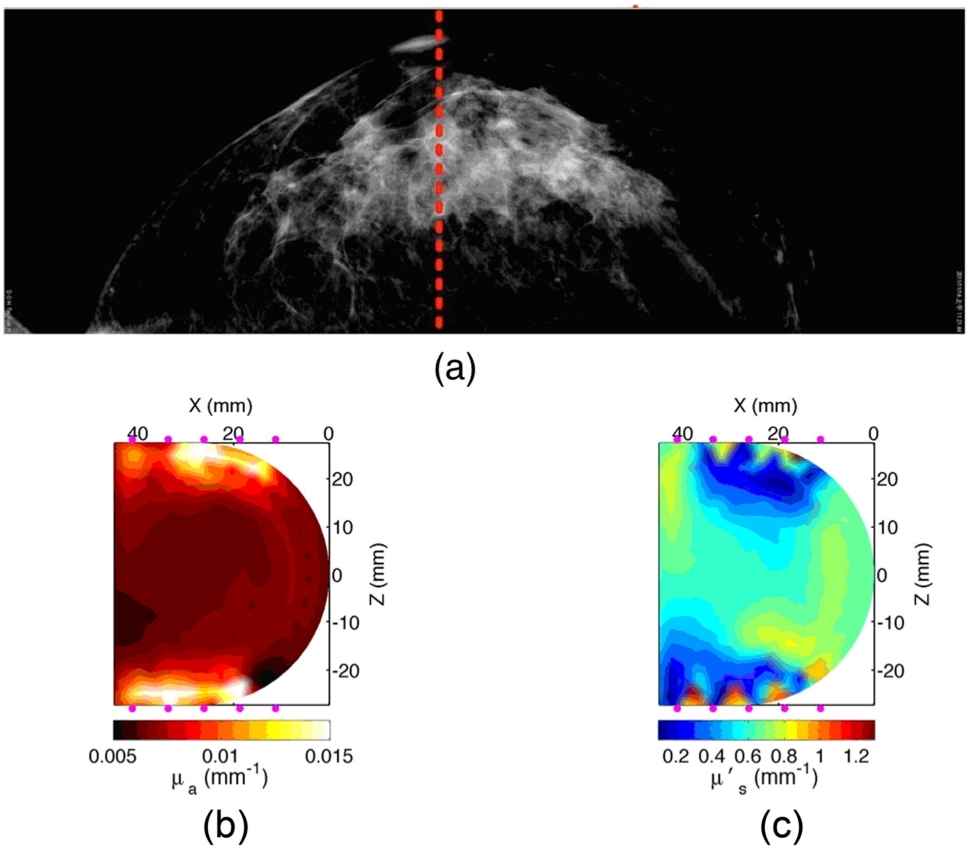

Fig. 4 The healthy right breast of a 53-year-old Taiwanese woman. (*a*) Craniocaudal mammogram, (*b*) absorption image, and (*c*) scattering image. (Source-and-detection combination: $5 \times 5 \times 2$)

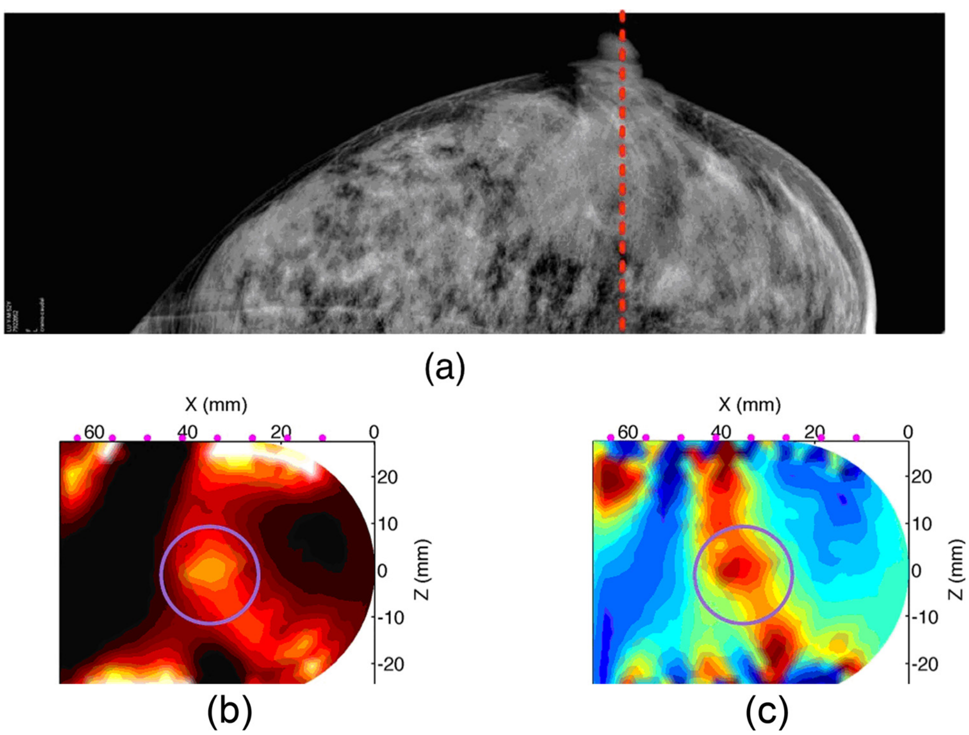

Fig. 5 Suspected abnormality in the left breast of a 53-year-old Taiwanese woman. (*a*) Craniocaudal mammogram, (*b*) absorption image, and (*c*) scattering image. (Source-and-detection combination:$8 \times 8 \times 2$)

3 Results

To illustrate the screening performance of breast tumor using the developed dual image modality, Fig. 4 demonstrates optical images from a healthy subject, a 53-year-old women with normal mammograms, where Fig. 4(*a*) displays the corresponding mammogram and Figs. 4(*b*) and 4(*c*) show μ_a and μ_s' images, respectively. The μ_a optical images of the normal breasts of the healthy subject are comparatively homogeneous and without increased absorption signals whereas μ_s' images show a slightly high contrast.

As a comparison, Fig. 5 takes account of a mammogram and optical absorption and scattering images from also a 53-year-old woman. The subject was also scanned through the use of optical imaging, shown as the following optical-property images. As can be seen in Fig. 5(*b*), a high contrast absorption distribution was observed in the region. Prior to the optical imaging, only the questionable tissue identified by mammography was known. A careful read of the handwriting mammogram report suggests that the mammogram indicates a suspected tumor as shown in the reconstructed μ_a image (Fig. 5(*b*)). It is noted that we calculated a ratio of the lesion over the whole region resolved by optical imaging 15/100 by using the threshold estimated from μ_a image.

4 Interpretation

As can be seen from Fig. 5, abnormalities with higher contrast of μ_a image appear in the scanned region. The homogeneous image (Fig. 4(*b*)) shown here clearly suggest the overall low background of the optical measurement and reconstruction. The images obtained present the common characteristic feature, that is, the absorption images relates to functional information indicating malignant and the structures, or say fibro-glandular distribution, can be imaged by μ_s' images.

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