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Co-Registered Photoacoustic and Ultrasound Imaging with Deep Learning for Breast Imaging and Tumor Localization

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Abstract:

We developed a novel breast imaging configuration that integrates Photoacoustic (PA) and Ultrasound (US) modes. A deep learning model trained via the clinical imaging results allows tumor localization within the breast tissue in three dimensions. © 2024 The Author(s)

PAUS dual modal imaging configuration:

The dual-modal system (OneTouch-PAT) consists of a portable laser with a 2.25 MHz central frequency, a water tank with an imaging window in the front, a height-adjustable lift table, and two linear scanning stages. The system acquired co-registered PA-US images with the patient in the standing pose, as shown in Figure 1(a).

During imaging, the transducer set was placed into the water tank and connected to two motorized translation stages to conduct a round-trip scanning: First, the transducer starts at the bottom left side of the breast and scans upward at 8 mm/s over 17 cm. After that, the scanning switches to the second translation stage to perform a 7-cm horizontal shift to the right. Finally, the transducer scans downward to cover the right side of the breast. This imaging protocol generates co-registered PAUS dual model images with a field of view of 17cm × 15cm within 1 minute. Figure 1 (b) shows a depth-encoded PA image after image combination.

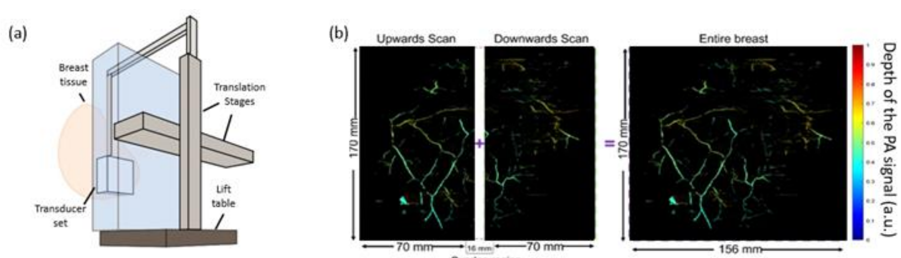

Figure 1. (a) The schematic of the OneTouch-PAT system and (b) a combined PA image generated by the round-trip scanning. Combining both trips generated an imaging window that was enough to cover the entire breast. The color of the PA signal, from blue to red, symbolizes the signal depth from shallow to deep.

Tumor feature analysis:

Figures 2 (a) and (b) show the depth-encoded PA image with the corresponding US image, and Figure 2(c) shows the overlapped PAUS image in the cross-section view (marked by the red dashed line). The US reveals the tumor lesion, and the PA images reveal the angiogenesis-induced feeding vessels that extended from the tumor position. The vascular information provided by PA can complement the structural details provided by the US, making PAUS data viable for tumor identification. So, we proposed a deep learning algorithm that used 3D Convolutional Neural Networks (3D-CNN) in the context of PAUS breast tumor identification.

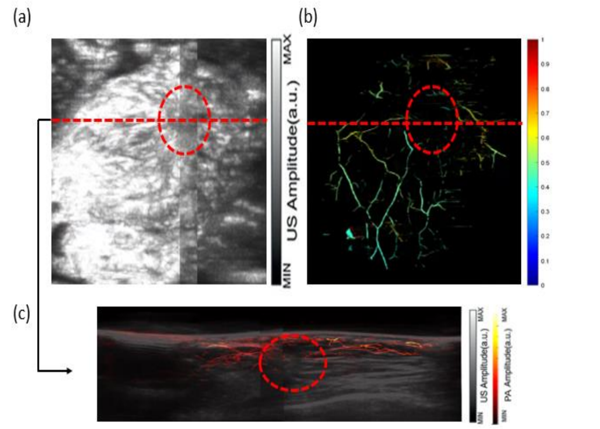

Figure 2. The frontal projection view of the (a) US and (b) the PA images, and the overlapped PAUS image in the cross-section view

3D-CNN model for tumor identification:

We constructed a user-interactive program to visualize the volumetric vessel structure and allow users to manually define the 3D coordinates from the whole 3D PAUS imaging result and crop the regional data chunks. We generated a dataset that contains 1,280 tumor-bearing PAUS chunks and an equal number of healthy counterparts for model training and testing. The co-registered PAUS dual modal data chunks are used as the model input. The PAUS data chunks go through a series of Conv3D and Max Pooling layers to extract modality-specific features. After that, the dense layers provide the model with the capacity to capture high-level, cross-modal relationships between the PA and US data, allowing for a more comprehensive analysis. Figure 3 shows the data generation and model training procedure.

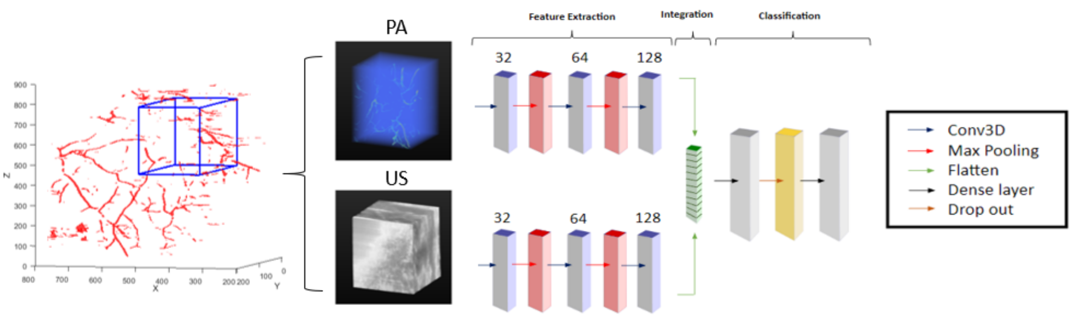

Figure 3. The dataset generation procedure and the architecture of the 3D-CNN model were used to classify the tumor-bearing PAUS images with healthy PAUS images.

We conducted a case study to verify the performance of the model. The model navigated through the PAUS image and sequentially extracted the PAUS data chunks to predict the presence of a tumor within the imaging window. Figure 4 shows the PAUS imaging results and the corresponding heatmap generated by the model. The patient has fair skin and a LUMA tumor located by the dashed circle. The heatmap highlighted the tumor position, thus confirming the ability of the model to localize the tumor lesion based on the PAUS data.

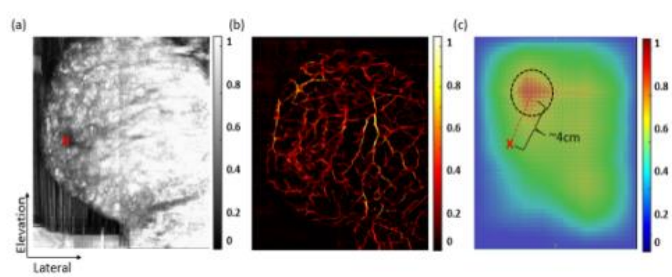

Figure 4. The (a) US and (b) PA imaging results of a patient with a LUMA tumor (marked by the dashed circle). Image (c) shows the heatmap generated by the model, which has the highest intensity at the tumor location.