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Image Infusion of Photoacoustic Imaging Based on Novel Adjustable Hand-held Probe

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***Abstract*— Photoacoustic imaging (PAI) is developing rapidly as a new kind of imaging technology. Conventional photoacoustic imaging devices are expensive, cumbersome, and illumination schemes are not adjustable, which significantly limit their development in clinical application. We designed an automated hand-held PA probe with adjustable illumination angle, spot size and distance. We also developed an adaptive control system for controlling the probe to achieve optimum illumination. Simulated scanning process on human brain model is performed to obtain photoacoustic images at various locations. Through image fusion algorithm, the images of each position are spliced and fused. Finally, the infused PA image of the human brain is obtained with higher contrast and fidelity.**

Keywords—hand-held, image fusion, automatic control, Co-simulation.

I. INTRODUCTION

Photoacoustic imaging, as an emerging and new kind of hybrid imaging technology is developing rapidly in recent years, because of its high imaging depth and imaging resolution compared with pure optic and ultrasound imaging, respectively [1-3]. The imaging mechanism consists of three steps: 1. Optical excitation. Chromophore (hemoglobin, melanin, etc.) in the tissue is illuminated by a short-pulse laser， then it induces thermal expansion and contraction. After that, the surrounded pressure of object is generated and emits ultrasound signals. 2. Collection of the sound signal. The ultrasound from inner tissue can be received by the transducer. 3. PA imaging reconstruction. The data from the transducer is extracted by algorithm, and reconstructs the PA images. For PA imaging, the imaging modality can be divided into two kinds: Photoacoustic microscopy (PAM) and photoacoustic computed tomography (PACT), both of which have achieved multi-scale and multi-contrast imaging performance, detecting endogenous chromophores (hemoglobin, melanin, etc.) or exogenous contrast agents. Due to the merits of its deep imaging depth and optical contrast, more and more research is concentrated on this emerging technology in recent years [4-6]. However， the existing system is still limited by bulky scale and high-cost, which get the PA imaging technology rid of preclinical and clinical applications widely[7].

To miniaturize the entire system, a very common idea is to put the optical system into the PA probe [8]. By coupling the external laser into the fiber, it is a good idea to further design a series of hand-held low-cost probes. For PA imaging, the optical excitation scheme can greatly affect the imaging performance. In general, there are two primary illumination schemes: bright field illumination and dark field illumination, each of which has its corresponding advantages and disadvantages[9]. From the previous research, everyone may be inclined to choose a light irradiation method that is more suitable for their target research object [10]. Once the fixed method is determined, the basic conditions of the experiment have been determined, and the results are produced thereafter. This may be influenced by the defined illumination protocol. The arguments about the quality of the irradiation program have not been reported in previous literatures. So designing a photoacoustic probe that can be switched freely between different illumination schemes seems to be a very rewarding task.

In this paper, we designed a photoacoustic imaging probe based on the research objectives that it can be adjusted with the researcher's different needs. Moreover, based on the predetermined function, We designed a suitable control system for the novel probe on scanning control. We scan multi-angle imaging based on the specified experimental phantom. In principle, a combination of countless illumination schemes can be obtained. On the other hand, Monte Carlo optical simulation is used to verify photon deposition in biological tissues.

II. SYSTEM DESIGN AND EXPERIMENT VERIFICATION

A. Probe design

The beam expander system consists of three linkage lens carriers and the corresponding lens. We designed a threaded connection for the linear movement of the multiple-changed group, and designed a ring cam pair using the curve for the movement of compensation sleeve group. In this way, the entire beam expanding system can realize the linkage expansion function with single power imputing. The specific design is shown in the Fig.1.

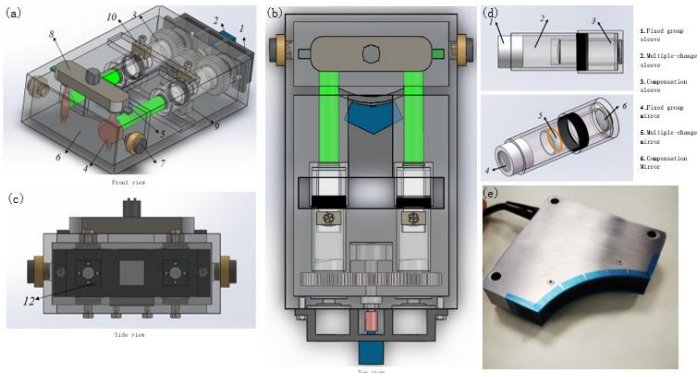

Fig.1 (a)~(c)The detail introduction of components. 1.Connection flange 2.step motor 3.SAU 4.Angle-adjustment mirror 5.UT 6.water tank 7.water intake/outlet 8.Angle-Adjustment Motor 9.Below bracket 10.upper bracket 11.coupling 12.Fiber connection (d) beam expander system. (e) photo of UT.

Angle conversion system is shown in the Fig. 1(a-8), we have designed a gear transmission mechanism for one end input and output at the same time, while ensuring that the output shaft is parallel and provides the function that the pair of the mirror can rotate contralaterally. The workflow of the entire system is as follows: The laser generated by the laser passes through the Y-shaped laser fiber and enters the probe at the same time. The emitted light is shaped by the light valve to obtain parallel lines incident light, with that coaxially incident into the beam expander system, then reach to the angle conversion system and eventually reach the sample surface.

B. Co-simulation for feasible verification

For the verification of the device function, we performed the co-simulation including Monte Carlo and k-wave simulation [11]. Based on the predetermined experimental sample, we simulated the deposition of photons in brain tissue through Monte Carlo simulation. Since the defined sample is much larger than the probe size, we use the local light illumination to simulate the whole probe scanning process. After obtaining the local sample light distribution map, the light distribution map is imported into the k-wave toolbox in Matlab for acoustic simulation. The photoacoustic signal is reconstructed by the DAS algorithm to obtain a partial photoacoustic image.

C. Image fusion experiment based on prefab sample

This experiment consists mainly of two parts :1.The construction of a probe-based photoacoustic system. 2. Photoacoustic image acquisition and fusion processing based on prefab sample fabricated by 3D printing machine shown in Fig.3. To verify the feasibility of the PACT system based on the new probe, we built a experimental system, which is shown in Fig.2.

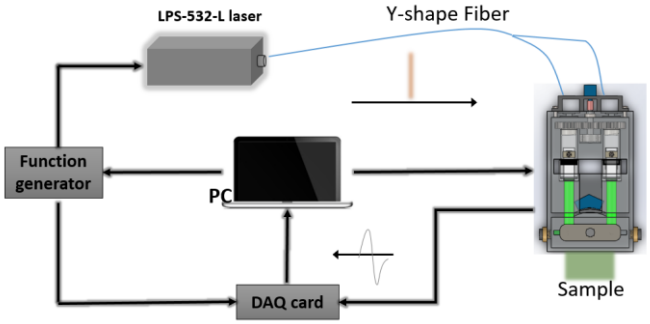

Fig.2 The experimental system based on the new probe

To generate a strong PA signal, we use high energy lamp pumped solid state Q-switched laser (LPS-532-L, CNI) as the laser source. With high peak power generated by EOM (Electro-optic modulation), the pulsed laser is coupled to a customized Y-shaped fiber that can carry high laser energy with the single multimode core via a fiber coupler. The laser beam from the fiber output is expanded by beam expander. Then the beam is reflected by the mirror to the sample surface. The PA signals detected by the ultrasound scanner are transmitted to a 32-channel DAQ board integrated into the ultrasound-imaging platform for further post-processing and image reconstruction. The original PA signal of sample collected by the system is processed by the wavelet de-noising method with adaptive threshold selection [12].

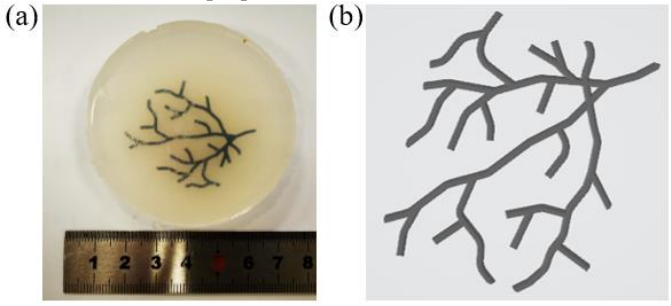

Fig.3 The phantom structure (a) the photograph of the phantom, and (b) the numerical model drawn in Solidworks.

III. EXPERIMENT RESULTS

A. Co-simulation results

After setting the parameters of Monte Carlo and k-wave programs, we executed the simulation process. For the purpose of simulating the probe scanning process, time loop is set up at equal intervals. We can simulate the scanning process by changing the nine preset positions one by one. We selected a slice layer with a height of 70 mm to observe the distribution of photons. The results produced by each specific lighting scheme are shown in the Fig. 4.

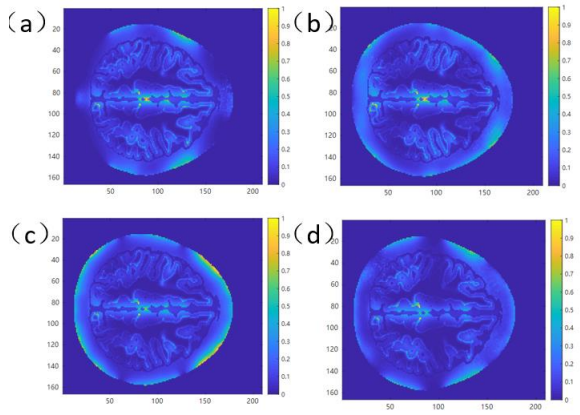

Fig.4. Monte Carlo light distribution simulation map. (a) light distribution at 45˚ (b) light distribution at 60˚ (c) light distribution at 75˚ (d) light distribution at 90˚

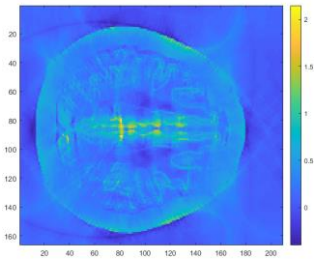

Fig.5. Full-angle scanning of local tissue PA images via k-wave simulation

B. PA imgae fusion results based on phantom

We performed the PA imaging experiments on different illumination schemes in Fig. 6. The consequences of image processing show that the picture fused can express more details which are not able to appear in single-illumination result, which can be seen in Fig. 7.

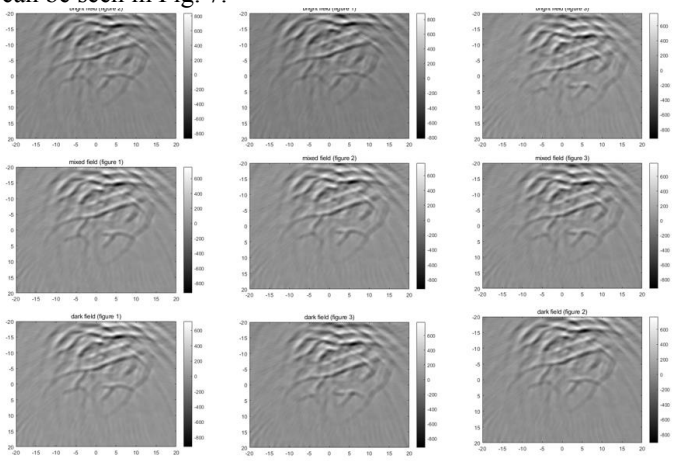

Fig.6. The PA images in different schemes based on the light-adjustable probe

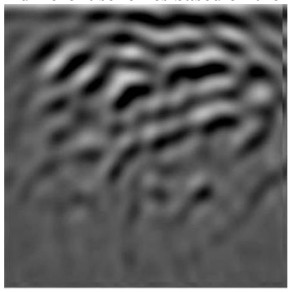

Fig.7 image after fusion

IV. Discussion and Conclusion

We designed a PA imaging probe, which can provide a function that gives different illumination， and the light parameters can be adjusted according to the requirements. Because of this function, we can change the light pattern without renewing adjusting the entire system, but just by altering the system configuration. we can also acquire many imaging results just by adjusting the control parameters. We performed co-simulation to show the optical distribution and wave production during the whole scanning processes. Results demonstrated that more detailed image after imaging fusion is acquired based on the proposed light-adjustable PA probe.

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