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TECHNICAL NOTE

Light-Emitting Diode Based Photoacoustic Imaging System

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Abstract

Purpose: A Photoacoustic Imaging (PAI) as a non-invasive hybrid imaging modality has the potential to be used in a wide range of pre-clinical and clinical applications. There are different optical excitation sources that affect the performance of PAI systems. Our goal is proving the capability of the Light-Emitting Diode (LED) based PAI system for imaging of objects in different depths.

Materials and Methods: In this study the Full Width of Half Maximum (FWHM) and Contrast to Noise Ratio (CNR) of LED-based PAI system is evaluated using agar, and Poly-Vinyl Alcohol Cryogel (PVA-C) phantoms.

Results: The results show that axial and lateral FWHM of the photoacoustic image in agar phantom 1%, are 0.59 and 1.16 mm, respectively. It is capable of distinguishing objects about 250 µm. Furthermore, one of the main improvements of photoacoustic images is achieved by proposed LED-based system that is a 26% higher CNR versus the ultrasound images.

Conclusion: Therefore, the provided technical characteristics in this study have made designed LED-based PAI system as a suitable tool for preclinical and clinical imaging.

Keywords: Photoacoustic Imaging; Light-Emitting Diode Based Photoacoustic; Phantom Imaging.

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1. Introduction

In the last decade, Photoacoustic Imaging (PAI) as a non-invasive hybrid imaging modality with tremendous potential in structural, functional, and molecular imaging, has the potential to be used in a wide range of pre-clinical and clinical applications such as tumor detection, cardiovascular disease, oral health, oncology and cancer staging, abnormalities of the tissue vasculature [1-6].

PAI detects the optical absorption contrast in tissue through the conversion of light to heat and thermoelastic effect, leading to the generation of acoustic waves [7, 8]. When the tissue is illuminated by short light pulses, the endogenous chromophores such as hemoglobin generate a Photoacoustic (PA) signal due to their optical absorption. In fact, PAI combines the high contrast of optical imaging techniques with the high spatial resolution of ultrasound imaging [2, 5, 9] (Figure 1).

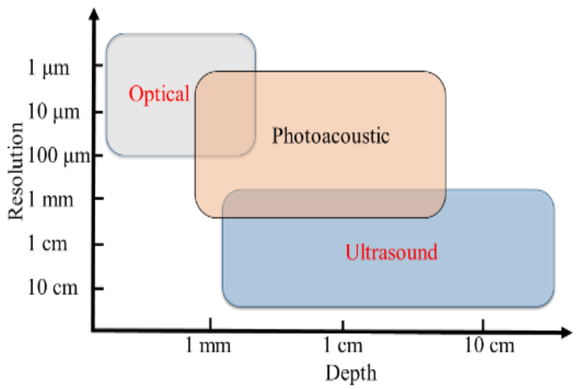


Figure 1. Comparison of photoacoustic imaging with ultrasound and optical imaging [10]

In PAI, the tissue is illuminated by a 5-150 ns light pulse; the absorbed optical energy leads to local temperature and subsequent thermal expansion leading to wideband ultrasound waves. The acoustic signal is directly proportional to optical fluence, and thus the optical excitation source is a key component of PAI systems. There are different optical excitation sources that affect the performance of PAI. The most commonly used light source in PAI systems are Q-switched Nd:YAG lasers (5). Pulsed lasers offer powers just below the ANSI limit for strong PAI signal generation. However, these lasers are also bulky, expensive, and delicate. Thus, recent efforts have focused on low-cost light sources such as Pulsed Laser Diodes (PLDs) and Light-Emitting Diodes (LEDs) to further facilitate widespread clinical utility of PAI [11, 12].

The LEDs are a category of light sources that has been recently used for PAI due to their compactness, low price, portable, long lifetime, the broad range of wavelengths, stable and high pulse repetition frequency. In this study, we focused on the design and develop of the compact LED-based PAI system. Our goal is proving the capability of the LED-based PAI system for imaging of objects in different depths.

2. Materials and Methods

We designed and developed a compact LED-based PAI system. The light source is custom-designed and includes an array of high power and intensity LEDs at 850 nm (SFH 4715S, Osram) with rise and fall time about 18 ns to illuminate an object in different pulse durations. The array of LEDs was embedded on a custom-designed transducer holder to generate a uniform light covering the entire field of view of the linear transducer. The LED driver using Field Programmable Gate Array (FPGA) is programmed to control the wavelength and generate the pulse duration.

The high-power LEDs can be operated in the pulsed mode using specific drivers. Conventionally, the LEDs are overdriven for better performance [13-16]. We need a power supply that could provide the instantaneous and high current to the LEDs. The routine power supply cannot provide the instantaneous current, and also is very expensive. So instead of it, we used the personal computer power supply (Green computer power supply, model: GP530A-EU). This power supply can provide the 24 Ampere. The LED driver designed in 4-layer a printed circuit board (PCB) in Altium designer 16.1 program as it is shown in Figure 2.

In this study the LED-based PAI system was evaluated using agar, and Polyvinyl Alcohol Cryogel (PVA-C) phantoms. The PVA-C material has been applied in the fabrication of phantoms for ultrasound, MRI and recently photoacoustic imaging. A 10% by weight PVA in water solution was used to form PVA-

C, which is solidified through a freeze–thaw process [17, 18].

In order to evaluate the LED-based photoacoustic imaging, we used two evaluation criteria: Contrast Noise Ratio (CNR) and Full Width of Half Maximum (FWHM). To evaluate the LED-based photoacoustic imaging quantitatively, the CNR metric was used with below definition:

$$CNR = 20\,log(\frac{|S_i - S_O|}{\sigma_O})$$

Where S_i and S_O are the average intensity inside and outside of the objects, respectively. The $\sigma_O$represents the standard deviation of the background. Furthermore, FWHM of the image in lateral and axial directions was used to quantify the reconstructed image quality.

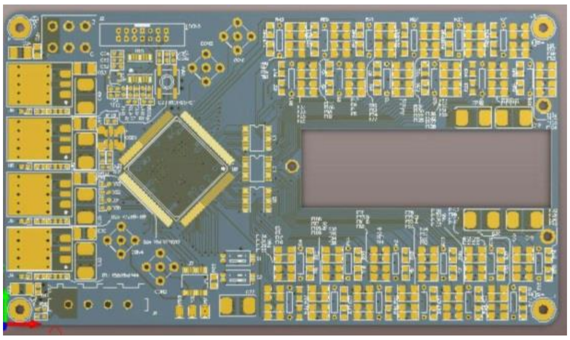


Figure 2. The LED driver as a 4-layer PCB designed in Altium designer

3. Results

The designed system was evaluated experimentally. An optical evaluation of the derived LED showed that the designed driver was capable of producing the pulses from 30 to 150 ns (Figure 3). These pulse durations are appropriate to generate the photoacoustic signal in phantom and tissue.

We have shown LED-based PA signal intensity in different depths for two different diameters of graphite in Figure 4. The results proved that our designed LED-based PAI system is able for imaging in PVAc phantom up to 22 mm. This system could demonstrate graphite with a 0.5 mm diameter in different depths.

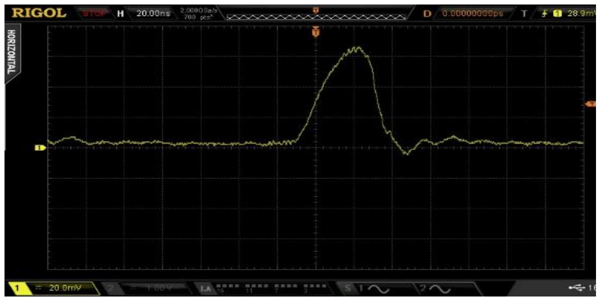


Figure 3. Optical pulse that is generated by high power LED montaged on driver board

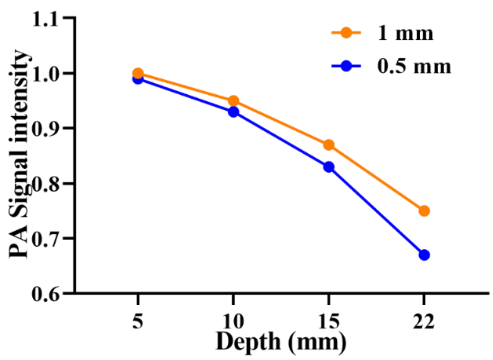


Figure 4. PA signal intensity in different depths for two different diameters of graphite

The results of the contrast of photoacoustic images of agar phantom show that the photoacoustic CNR is 20.5 dB and the CNR of ultrasound at the same condition is 16.3 dB (Figure 5).

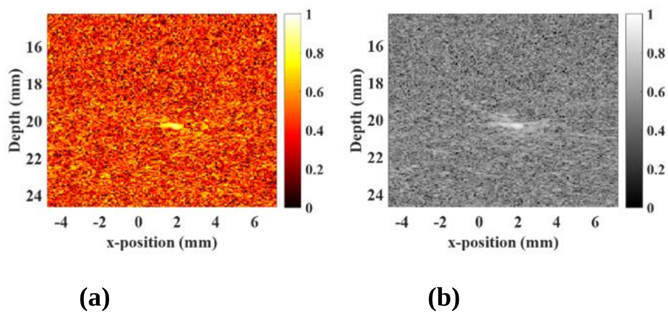
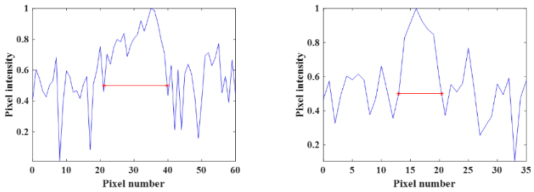


Figure 5. a) PA and b) Ultrasound image of object in depth 20 mm in agar phantom 1%

The axial and lateral FWHM in DB106 acupuncture needle (Suzhou Dong Bang Medical Co, Ltd) with 250 µm diameter in 20 mm depth in agar phantom 1% are 0.59 and 1.16 mm, respectively (Figure 6).



(a) (b)

Figure 6. a) Lateral and b) Axial profile of needle photoacoustic image in depth 20 mm

4. Conclusion

PAI may overcome the low precision of the US for evaluation of the deeper objects while at the same time adds the advantage of the optical imaging for depicting the superficial parts. Also, the illumination system was experimentally evaluated. The results showed that the designed PAI system is capable of imaging in different depths and up to 22 mm. Our LED-based PAI system FWHM in axial and lateral are about 0.5 and 0.9 mm, respectively. It is capable of distinguishing objects about 250 µm. The CNR of photoacoustic images is about 26% better than ultrasound images. The designed system is able to show the graphite, needle, blood in tissue-like phantom. The provided technical characteristics have made our system a suitable tool for imaging of phantom, animal, and preclinical imaging. Furthermore, it could be added to navigation systems as an interventional imaging to provide more information during surgery.

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