Time-gated Parallelised Interrogation of a Fabry-Perot Ultrasound Sensor Using a Camera for Fast Photoacoustic Tomography

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Abstract: Fabry-Perot scanners are typically read out in a sequential manner. To speed up the image acquisition, an alternative is to use a widefield illumination approach and measure the reflected light in parallel using a camera.

1. Introduction

Fabry-Perot (FP) based scanners can provide photoacoustic images of soft biological tissue with high contrast and spatial resolution. Early configurations read out the sensor in a sequential manner by scanning a single focused interrogation beam over the sensor and measuring the reflected light. The acquisition time is however relatively long. For example, for a standard photoacoustic image composed of 20,000 spatial sampling points, the acquisition time is 100 seconds when using an excitation source with a 200 Hz pulse repetition frequency (PRF). One approach to speed up the acquisition is to simultaneously scan multiple excitation beams over the sensor[1]. However, the cost and technical complexity of this approach limits the degree of parallelisation that can be achieved and, in practice, scanning more than 100 beams is likely to be very challenging. An alternative is to use a widefield illumination approach, where a large collimated beam is incident on the sensor and the reflected light is captured by a camera. The interrogation beam is pulsed so that each frame acquired by the camera represents a snapshot of the acoustic pressure over the surface of the sensor. By capturing multiple frames while adjusting the time delay between the firing of the excitation laser used to generate the photoacoustic signal and that of the interrogation laser, the complete time record of the photoacoustic signals over the sensor surface can be retrieved. The advantage of this approach is that each pixel of the camera corresponds to a sensing point on the FP sensor. Since the number of camera pixels can readily exceed 10^4, this approach offers the prospect of achieving a fully parallelised sensor read-out thereby enabling sub-second 3D image acquisition times. We previously demonstrated proof of concept in a preliminary study[2] based on simple phantoms. Here, we build on this early study by first demonstrating that 3D photoacoustic images can be obtained with acquisition times as low as 0.2 seconds and subsequently demonstrate that adequate sensitivity is provided by the camera based FP scanner for in-vivo imaging.

2. Method

The imaging system is shown in fig. 1 (a). A 7 mm diameter (FWHM) interrogation beam was formed by collimating the output of a single mode fibre using an optical lens. The beam was then guided through a polarisation beam splitter onto the Fabry-Perot sensor and the reflected light imaged on to the camera using an optical lens. The interrogation beam consisted of a 30 ns laser pulse at 1550 nm. The camera was composed of 258 by 320 pixels (82,560 pixels in total) with a pixel size of 30 µm by 30 µm, forming an area of 9.6 mm by 7.68 mm. The maximum frame rate that the camera could operate at was 200 Hz when using all available pixels; however, higher frame rates in the kHz range can be achieved by binning pixels. For example, a 1 kHz frame rate can be achieved when using only 100 x 100 pixels. To acquire the whole time record of the photoacoustic wave, 200 snapshots were acquired by varying the time delay between the firing of the excitation source and the interrogation pulse in steps of 20 ns, corresponding to a total time record of 4 µs. To demonstrate the speed benefit of this approach, the imaging system was combined with a custom built 1064 nm fibre laser[3] with a variable PRF ranging from 100 Hz to 1 kHz. A phantom composed of two black absorbing ribbons immersed in water was then imaged, first when operating at a PRF of 200Hz and acquiring data from all 82,560 pixels of the camera, then when operating at a 1 kHz PRF and using a reduced number of pixels (100 x 100). Subsequently, to demonstrate that the system is sensitive enough to acquire in vivo images, the palm of a human hand was imaged, using a Nd:YAG Q-switched laser with a PRF of 20 Hz as an excitation source. A time reversal algorithm was used to reconstruct the photoacoustic images.

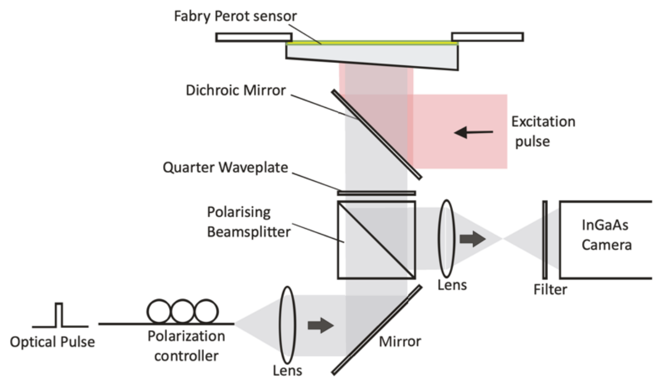

Fig. 1. Schematic of the camera based FP scanner system. The parallel readout is based on illuminating a larger region of the Fabry Perot sensor and taking multiple snapshots of the acoustic pressure using an InGaAs camera.

3. Results

Fig. 2 (a) and (b) show the reconstructed 3D photoacoustic images of the ribbon phantom when operating at a 200 Hz and 1 kHz, respectively. The former was acquired in 1 second, whereas the latter was acquired in 200 ms. The two ribbons can clearly be identified in both images, although the field of view is reduced to 3 mm by 3 mm in the latter due to the need to bin pixels. Fig. 2 (c) shows the reconstructed photoacoustic image of a human hand where a number of vessels can be identified, the largest and the smallest being approximately 630 and 200 μm in diameter, respectively. A maximum depth penetration of 3 mm was achieved. The complete time record (200 points) was recorded in 10 s.

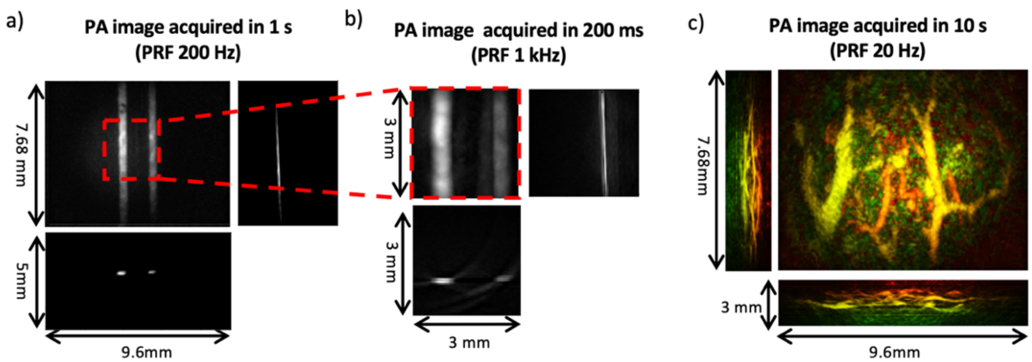

Fig. 2. Parallel read-out of a FP sensor; (a) and (b) Photoacoustic image of a ribbon phantom, acquired when operating at a laser PRF of 200 Hz and 1kHz respectively, (c) Photoacoustic image of the palm of the human hand, obtained when operating at a laser PRF of 20 Hz.

4. Conclusion

These preliminary experiments have demonstrated that 3D photoacoustic images can be acquired in 200 ms when operating at a PRF of 1 kHz. This represents a 500-fold reduction in imaging times when compared to the standard FP scanner based on scanning a single interrogation beam. Moreover, the capability of the camera based system at acquiring in-vivo images was also demonstrated. The proposed talk will build on these preliminary results and demonstrate that further improvements in terms of image contrast to noise ratio can be achieved by; (1) operating at a more suitable excitation wavelength; for example, at 808 nm water absorption is an order of magnitude smaller than at 1064 nm while the absorption coefficient of blood is similar to that at 1064 nm; (2) using a camera with an increased number of pixels (e.g. 1280×1024) to further improve the contrast to noise ratio of the photoacoustic image as the reconstruction algorithm effectively spatially averages the recorded traces.

5. References

[1] N. T. Huynh *et al.*, “High resolution 3D photoacoustic scanner for clinical vascular imaging applications (Conference Presentation),” in *Photons Plus Ultrasound: Imaging and Sensing 2020*, 2020, vol. 11240.

[2] T. J. Allen, E. Zhang, and P. C. Beard, “Fully parallelised read-out of a Fabry-Perot ultrasound sensor using an InGaAs camera for fast photoacoustic imaging (Conference Presentation),” in *Photons Plus Ultrasound: Imaging and Sensing 2020*, 2020, vol. 11240.

[3] T. J. Allen *et al.*, “High pulse energy fibre laser as an excitation source for photoacoustic tomography,” *Opt. Express*, vol. 28, no. 23, p. 34255, Nov. 2020.