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High-speed Photoacoustic Microscopy Using MEMS Mirror with a Correction Method for Distortion Caused by the Mirror Scanning

ミラー走査由来の歪みに対する補正手法を適用した MEMS ミラー駆動式高速光音響顕微鏡

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1. Introduction

Photoacoustic microscopy (PAM) is an implementation for high resolution in photoacoustic imaging, and allows for selective and functional imaging of micro-tissues and -circulations[1]. However, conventional PAM with mechanical scanning stages is very time-consuming to imaging. In particular, optical resolution PAM (OR-PAM) requires a lot of scanning point because of its high lateral resolution, consequently it takes ~30 minutes for an imaging in 2 mm x 2 mm[2]. This makes not only the motion artifact but also the difficulty of the biological interpretation of the imaging result. Thus, a fast-scanning PAM is required for its biological applications, especially in OR-PAM.

Recently, MEMS mirror is expected as a solution for high-speed PAM. It scans optical and ultrasonic beams by controlling the angle of the mirror with a sinusoidal driving voltage, providing much faster than the mechanical scanning[3]. However, when the mirror is scanned by sinusoidal, the nonlinear behavior of scan angle is happened. To correct the distortion, in the previous study, the following two parameters had to be verified in detail in advance.: 1)The characteristics of the MEMS mirror such as the voltage-angle relationship. 2)Working distance from the mirror to the focal point. These verifications are very complicated and time-consuming. Therefore, a simple method to correct the distortion is needed for ease of the applications.

In this study, we develop an OR-PAM using MEMS mirror (MEMS-OR-PAM), and propose a novel method to simply correct the distortion caused by the nonlinear angle scanning of the MEMS mirror.

2. Materials and Methods

2.1 Experimental Setup

Fig. 1 shows the developed MEMS-OR-PAM system. This system employed a Nd:YAG 532 nm laser (10 ns pulse width; 10 kHz pulse repetition rate) as the laser source. The emitted laser beam is coupled through the objective lens (OL1) into a multimode fiber (FC, 10 μm core diameter). The laser beam from the fiber output was shaped by a collimating lens (CL) and then split into two beams by a beam splitter (BS). The One was directed to the photodetector (PD) as a trigger signal for data acquisition timing, and the other beam was tightly focused by an Achromatic Doublet lens (OL2, 60 mm Focal Length; 0.2 NA). The focused laser beam was gone through a Opto-Acoustic Beam Combiner (BC) to coaxial and confocal with an acoustic focus consisting of an unfocused ultrasound transducer (UT, 50 MHz center frequency) and an acoustic lens (AL, 0.25 NA). The Opto-Acoustic Beam is reflected by the 1-Axis-Waterproof-MEMS (1A-WP-MEMS) mirror (AL coating) and irradiated to the sample. The photoacoustic signals are detected by an ultrasound transducer, amplified by two series connected amplifiers (AMP, 46dB Gain), and then recorded by a high-speed data acquisition card (500 MS/s Sampling Frequency).

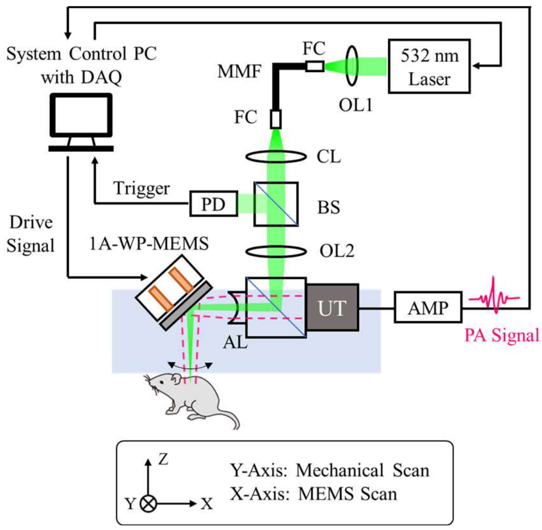

Fig. 1 Schematic of MEMS-OR-PAM system

For 3D volumetric data acquisition of the signals, angular scanning in the X direction with a 1A-WP-MEMS mirror and mechanical scanning in the Y direction with a mechanical stage were performed. The driving voltage for the angular scanning of the 1A-WP-MEMS mirror was driven by a sinusoidal wave for fast scanning.

2.2 Correction for distortion caused by MEMS scan

Fig. 2 shows the linear/nonlinear behavior of angle scanning by MEMS mirror. Since PA signals are acquired at the timing of laser PRF, the acquired PA lines assumed to transition at a linear angle before considering the non-linearity, as shown in Fig. 2(a). To correct it to the actual nonlinear behavior as shown in Fig. 2(b), the following equation is introduced,

$$\theta_{nonlinear} = \frac{\theta_{scan}}{2} \sin\left(\frac{\theta_{linear}}{\theta_{scan}}\pi\right), \qquad (1)$$

where $\theta_{nonlinear}$ is the nonlinear scanning angle, θ_{scan} is the range of scan angle, and θ_{linear} is the linear scanning angle.

Here, in order to apply Eq. (1) and convert the polar coordinates to the cartesian coordinates, prior knowledge of θ_{scan} and r (length from the mirror, consisting of working distance (WD) and acquired PA lines) is required. In this study, we introduced a novel method to calculate them by imaging a ruler, and simply correct the nonlinear distortion. This method is performed by following 6 steps.

1) PA imaging of ruler in the interest region (2 x 2 mm^2 in this study) by adjust the driving voltage.
2) Set the value of WD virtually and calculate r.
3) Calculate θ_{scan} from the WD and the imaging range in the X direction (2 mm in this study).
4) Calculate $\theta_{nonlinear}$ by using Eq. (1).
5) Cartesian coordinates transformation, and image reconstruction.
6) Repeat 2) - 5) while varying the WD to get the image completely corrected the distortion.

After completing the above steps, the effectiveness of this method was verified by comparing C-mode and B-mode images with Raw Data / Linear Distortion Corrected / Nonlinear Distortion Corrected (proposed).

3. Results and Discussions

Fig. 3 shows the result of the comparison. In the result of Raw Data, both C / B-mode images are distorted as shown in Fig. 3(a)(b). When only the linear scan angle characteristics (Linear Distortion) are corrected by polar transformation, the image is still distorted as shown in Fig. 3(c)(d). On the other hand, by using the introduced method, Nonlinear

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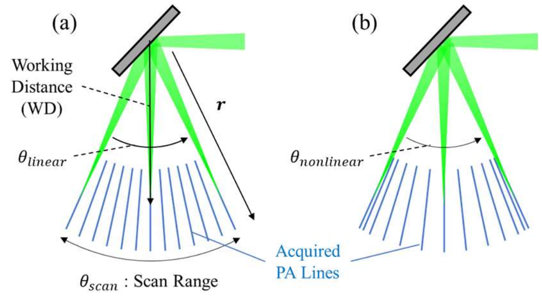

Fig. 2 Distortion caused by MEMS scanning, (a) Linear Distortion, (b) Nonlinear Distortion.

Distortion is simply and completely corrected as shown in Fig. 3(e)(f), under the robust value setting of WD=7 mm and θ_{scan}~16°.

Even in the in-vivo imaging with developed, by performing the proposed method once in advance, the distortion can be easily corrected.

4. Conclusion

In this paper, we developed MEMS-OR-PAM for high-speed imaging. Also, we proposed a method that easily considers the non-linearity of the scanning angle of the mirror, and successfully removed the non-linear distortion of the photoacoustic image.

References

1. J. Yao et al.: Nat. Methods, **13**(8), (2016).
2. J. Yao et al.: Laser Photonics Rev., 7, (2013)758.
3. J. Y. Kim, et al.: Sci. Rep., **5**, (2015)7932.

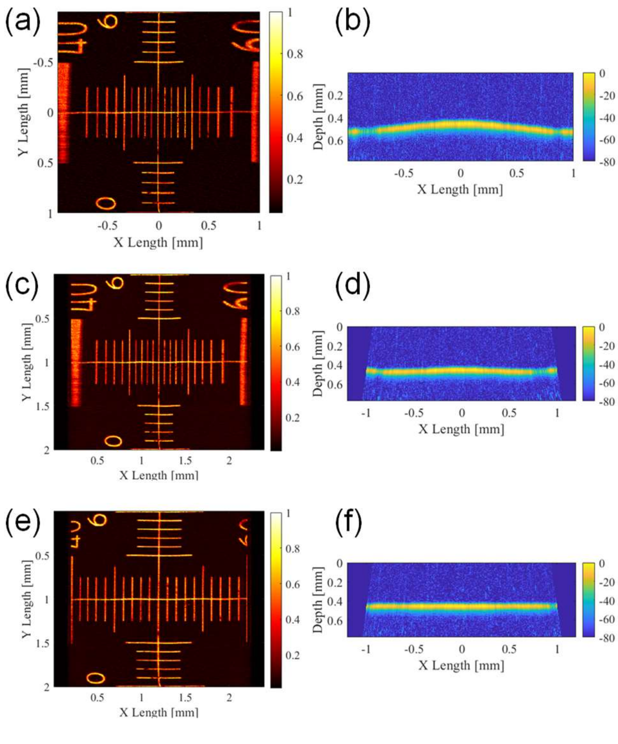

Fig. 3 C-mode (left) and B-mode (right, used the center line of C-mode) images of ruler, (a, b) Raw Data, (c, d) Linear Distortion Correction, (e, f) Nonlinear Distortion Correction.