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Simulation Analysis of High Frame Rate and High Quality Photoacoustic Computed Tomography Using Coded Excitation

符号化を用いた高速かつ高画質な光音響トモグラフィのシミュレーションによる解析

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1. Introduction

Photoacoustic Computed Tomography (PACT) records signals from a wide range of angles to achieve uniform, high-resolution images. A high-power laser is generally used for PACT, but the long acquisition time is a problem due to the low pulse-repetition frequency (PRF). For PACT, this degrades image resolution and contrast because it is hard to scan with a small step interval, and a fast image acquisition system is especially desired in *in vivo* measurement to avoid motion artifacts. This problem can be resolved by using a high PRF laser, which at the same time only provides weak energy. Averaging measured signals many times mitigates the low signal-to-noise (SNR) issue, but the PRF is restricted by the acoustic time-of-flight, so this is a new source of measurement time increase.

Here, we present the coded excitation approach, which is usually used to increase the SNR by transmitting pulse in high PRF over the acoustic time-of-flight limitation, to speed up the scanning of PACT. In this paper, periodic and unipolar M-sequences (PUMs) [1] is focused, since it is uniquely beneficial for PACT to improve scanning pitch. Different from aperiodic sequence, the start point of decoding can be set in any code in the periodic sequence, so that high temporal resolution information can be utilized. Herewith, measurement points can be increased, and the improvement of reconstructed image quality for the same measurement time is expected. To validate the proposed idea, we conducted simulation studies and compared the performance of coded excitation to that of continuous data acquisition method [2].

2. Theory and Method

2.1 Construction of PUMs

Periodic and unipolar m-sequences (PUMs) is generated with maximum-length sequences (m-sequences). M-sequences are bipolar sequences that can be generated with a linear feedback shift register. PUMs are unipolar sequences consisting of {1, 0}, which is selected from positive codes of bipolar m-sequences consisting of {1,-1}. The code length of PUM is $N = 2^L - 1$, where L is the size of the linear feedback shift register used to generate the m-sequences. Signals can be enhanced by decoding periodically sent PUM using bipolar sequences, and there are no coding artifacts at all for a single wavelength.

2.2 PACT Using Coded Excitation

To compensate weak energy in high PRF laser, the signals received at the same position can be averaged, but it takes time. Herein, we used a continuous data acquisition method, by utilizing the rotation stage which is revolved to a predefined speed and continuously moved for the entire 360 revolution. Then, a hydrophone is used to record all directional information of the subject. Universal back projection algorithm can be used for reconstruction [3]. Coded excitation is applied into this system. The PRF is thus not restricted to acoustic time-of-flight, and consequently acquisition time can be shortened and the SNR will increase for the same measurement time.

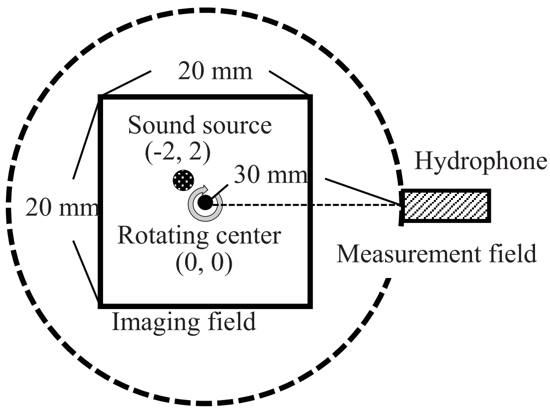

Fig. 1 Simulation setup for PACT.

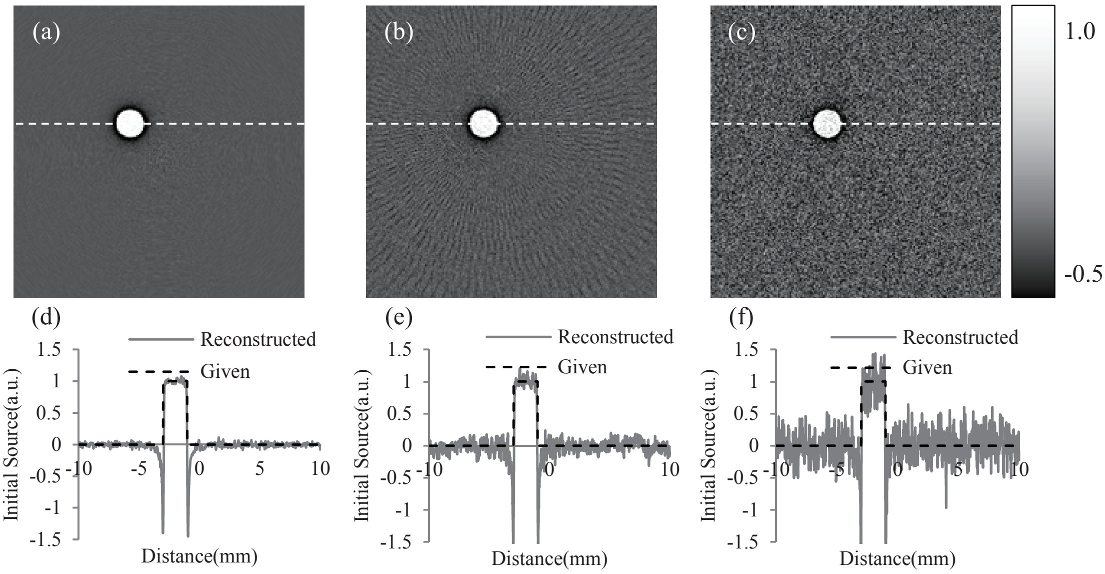

Fig. 2 Reconstructed images (a-c) and profile of initial source along broken line (d-f); (a), (d) using coded excitation and changing start point of decoding, (b), (e) using conventional coded excitation, and (c), (f) using continuous data acquisition method.

2.3 Simulation setup

The simulation setup is displayed in Fig. 1. The rotation stage was revolved 360 degree for 0.06 seconds while the data was collected continuously. The PRF of the laser assumed was 1 MHz. The sampling frequency was 50 MHz. The radius of the optical absorber was 1mm and the position was slightly out of the center. The distance between rotating center and hydrophone was 30 mm. 511-bit PUMs were sent 120 times to acuqire 360 degree information. For comparison, continuous data acquisition method without applying any encoding for the same measurement time was also simulated. Gaussian noise (-10 dB) was added to simulate white noise.

3. Result

The result is shown in Fig. 2. Figures 2(a-c) show the reconstructed images for same measurement time. Figure 2(b) was the result of coded excitation, and decoding were performed for the first bit of a sequence, thus the number of measurement points was 120. This is a classic way to decode encoded signals. However, in another coded excitation result as shown in Fig. 2(a), decoding was performed with the interval of 1 bit, and the number of measurement points was extended into 511 multiples 120. It becomes possible because of using periodic sequences, and it's a unique improvement in the method we proposed. Finally, Fig. 2(c) is the result without using coded excitation, and the number of measurement points was 1533 because of the limitation by the acoustic time-of-flight. Figures 2(d-f) showed the quantitative evaluation of initial source of Figs. 2(a-c) respectively, which visualize the beam profile across at the center of sound source. It was concerned that the decoded signals contain decoding artifacts because of the contamination of signals acquired from neighboring angles. However, Figures 2(a-b) and Figs. 2(d-e) show that the effect was negligible, because the transmission PRF was sufficiently fast. Compared to Fig. 2(f), Fig. 2(e) indicates that coded excitation improved the SNR of reconstructed images for the same measurement, and further improvement was confirmed by changing the starting point to decode in Fig. 2(d).

4. Discussion and Conclusion

We demonstrated the feasibility of the PACT using coded excitation through simulation. Coded excitation improved the SNR not only because of the temporal encoding, but also utilizing small scanning pitch corresponding to each code. It requires 40 times more the measurement time if we want to achieve same amount of SNR improvement as that in Fig. 2(a) without using coded excitation under the same condition as this simulation.

As future works, we will validate the benefits using coded excitation by conducting experiments.

5. References

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