Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 269-270
8-10 November, 2011

Simultaneous multispectral coded excitation using Gold codes for photoacoustic imaging

光超音波イメージングのための Gold Code 符号化による多波長同時励起法

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1. Introduction

Photoacoustics (PA) is a new imaging modality based on the generation of ultrasound by laser irradiation [1]. When a nanosecond pulsed laser irradiates biological tissue, thermo-elastic expansion will cause ultrasonic waves that can be used for imaging by mapping the amount of light absorption by using ultrasound transducers. PA imaging is real-time imaging that combines high resolution and relatively high penetration depth of ultrasound imaging compared with light and the high contrast of optical imaging. Furthermore, applying light absorption characteristics using multispectral irradiation enables us to monitor functional information like the blood oxygenation.

A problem with PA is that the exciting light will be attenuated because of diffusion with depth. Furthermore, improving the signal-to-noise ratio (SNR) requires repeated irradiation, and it is difficult to maintain simultaneity. In addition, obtaining multispectral information normally takes time corresponding to the number of waves, and further keeps away from real time.

Coded excitation can be used to solve this problem by coding the laser pulses. Furthermore, the intensity of the received signal can be enhanced by compressing the coded signals. Using code orthogonality will enable simultaneously distinguishing multispectral photoacoustic signals and facilitating real-time imaging. Previous studies have proposed Orthogonal Golay code for multispectral coded excitation [2].

In this paper, we propose Gold codes that exhibit reasonable aperiodic cross-correlations and off-peak autocorrelations for generating multispectral PA signals simultaneously and more effectively.

2. Theory and Method

2.1 Property of Gold codes

A Gold code is a type of binary sequence created for a preferred pair of maximum-length sequence [3]. Gold codes have better aperiodic cross-correlation properties than maximum length sequences. Furthermore, the set of the $2^{n}-1$ exclusive or's of the two sequences in their various phases is a set of Gold codes which will expand the choice for multispectral irradiation.

The properties of aperiodic cross-correlation and autocorrelation of Gold codes are depending on code length. Fig.1 shows the main lobe to the peak side lobe of autocorrelation value ratio (MPAR) and the peak cross-correlation value ratio (MPCR).

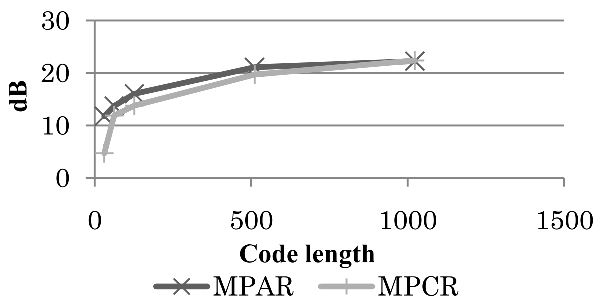

Fig.1 The property of Gold code

For code excitation in PA, it is necessary to transmit positive and negative signs separately. To send {[1 -1]} codes, for instance, they are first reformatted as two unipolar codes {[1 0], [0, 1]}. Since PA signals can be represented as linear systems, original codes are reconstructed by subtraction.

Assuming the range of side lobes to be small compared to the noise for evaluating SNR improvement, the mean-square-error (MSE) of the decoded signal for unipolar Gold Coding (gold) is

$$\sqrt{\mathrm{MSE}_{\mathrm{gold}}} = \sqrt{2\sigma^2/_N} \quad (1)$$

with $N = 2^L - 1, L \in \mathrm{N}$ being the code length and distributed white noise with variance σ^2.

If the time between two light pulses is defined as τ_L, and the time it takes for the pressure waves to travel from the farthest absorber with a distance z_a to the ultrasound transducer at the speed of sound c_0, the acoustic time-of-flight is

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$$\tau_E = {}^{z_a}/_{c_0}. \qquad (2)$$

Total sending time of Gold code is

$$T_{\text{gold}} = 2((N_{\text{gold}} - 1)\tau_L + \tau_E). \qquad (3)$$

In multispectral photoacoustic coded excitation, when coded laser pulses are irradiated from different waves simultaneously, each spectral component can be acquired separately from compression using codes of requested wavelength because only specific signal can be detected by autocorrelation; other signals will be offset by cross-correlation.

2.2 Simulation of Gold Coding

The effect of multispectral photoacoustic coded excitation using Gold Coding was estimated, assuming the situation of simultaneous measurement of four deferent wave lengths. Four 1023-bit unipolar Gold codes were prepared to simulate the separation. Gaussian noise (-10dB) was added.

2.3 Experimental Setup

Coded excitation using Gold code is tested using the setup displayed in Fig.2. In this setup, a code pattern generator triggers a Nd:YVO_4 laser module (MATRIX532-8-100, Coherent). The wavelength of the laser is 532 nm and the pulse energy is 77 μJ per one shot. Each pulse was excited for 20ns, and the pulse repetition frequency (PRF) was 50 kHz. A 0.3mm wire was used as an absorber with Gold coded excitation of a 1023-bit code, and photoacoustic signal was detected by hydrophone.

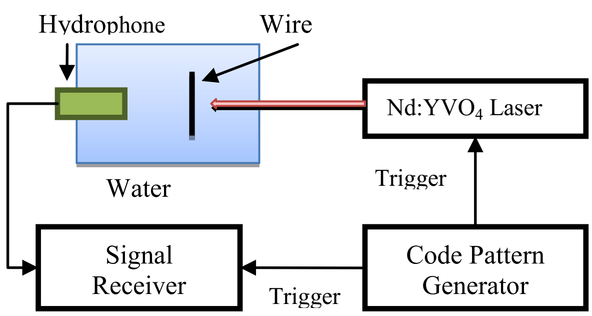

Fig.2 Experimental setup for measuring PA signal

3. Result

3. 1 Simulation Result of Gold Coding

The Simulation conditions were presented in previous section. By decoding measured signals using the code what want to pick up, it was succeeded to separate each of 4 wave length signals separately. SNR gain is 18.54dB, compared with original signal without coded excitation. Assuming a PRF of 1MHz and an acquisition depth of 50 mm, the sending time for a 1023-bit Gold code is equivalent to the time needed for acquiring the 16 impulse responses. The SNR improvement is 6.31dB, compared with 16 times averaging.

3. 2 Experiment Result of Gold Coding

The received PA signals of Gold code with 1023bit code length and 20 ns duration are presented in Fig.3. The SNR improvement was 23.83 dB compared with a signal without coded excitation, successfully demonstrating that Gold Coding can be applied for PA imaging.

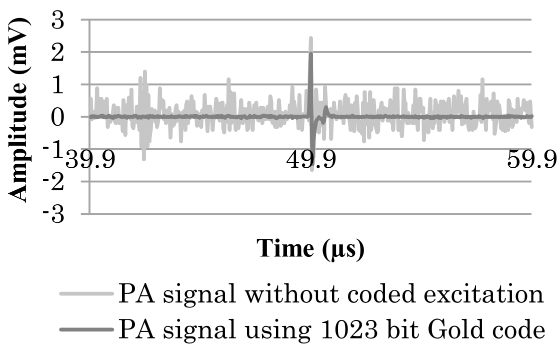

Fig.3 Received PA signals

4. Discussion and Conclusion

We demonstrated the feasibility of simultaneous multispectral coded excitation using Gold codes for photoacoustic imaging is shown by simulation and experiment. For multispectral coded excitation, Gold codes only need to be sent once compared with Orthogonal Golay Codes that needs to be sent a number of times equivalent to the number of waves. Furthermore, Gold codes can reduce the sending time for 1 out of wave numbers and realize truly simultaneous measurement.

Gold codes become more effective as the number of spectral components increases. To analyze side lobes more precisely, it is necessary to generate images and examine them more deeply.

Acknowledgment

This work was supported by Grant-in-Aid for Scientific Research (A) [22240063], MEXT, Japan.

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