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Research Paper

Research on barker coded excitation method for magneto-acoustic imaging

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ABSTRACT

Functional imaging method of biological electrical characteristics based on magneto-acoustic effect gives valuable information of tissue in early tumor diagnosis. Common exciting and measuring method is to use single pulse. The imaging quality and the imaging speed are limited by the signal to noise ratio (SNR). In this study, we propose a processing method based on coded excitation and pulse compression to improve SNR of magneto-acoustic imaging. Barker code is widely used in ultrasonic signal processing, which can effectively improve the signal to noise ratio. It is introduced to increase SNR of the magneto-acoustic signal. Simulations on magneto-acoustic signal and pulse compressed signal under Barker coded excitation with a group of bit lengths are computed. Experiments on sample made of pork and graphite slices are done to validate the proposed coded excitation method. The pork sample is imaged to validate this method. SNR is investigated using Barker codes with different bits. The results showed, the SNR of magneto-acoustic signal is improved by the coded excitation. When 13 bit Barker code mode is adopted as the exciting signal, SNR improved by 21.5 dB. For a similar SNR improvement, the processing time of coded excitation method can be shortened by 95.8% compare with single pulse excitation method. In a conclusion, the coded excitation method is effective to improve the magneto-acoustic signal SNR and imaging quality. It also improves the magneto-acoustic imaging speed.

1. Introduction

Dielectrics characteristics reflect physiological and pathological conditions of the tissues [1–3], and implies its potential value in diagnosing some relate diseases. Magneto-acoustic imaging [4,5] based on Hall effect [6] is a newly modality for imaging electrical parameters of biological tissue [7,8] and also helpful for sensing biological micro-currents [9,10].

Signal to noise ratio (SNR) is one of the most concerned technical parameters in this method. It has important influence on imaging quality and screening accuracy of disease. Due to the weak magneto-acoustic signals, and the detector is influenced by the high frequency electromagnetic field, SNR is low. Besides, the magneto-acoustic imaging mainly uses single pulse excitation [11,12] and detects the magneto-acoustic response pulses for imaging the conductive distribution of the tissues. In order to obtain high resolution imaging, the width of the single pulse should be short enough. However, the short duration of the pulse which carries conductivity information makes the average power low, and lead to low SNR of the magneto-acoustic signal. The usual processing method to improve SNR in pulse mode is to average the waveform. But the long time for signal acquisition and processing extend the total imaging time. For example, to get a 40 dB SNR improvement, 10,000 times averaging is needed. This means the magneto-acoustic imaging will last long and present low efficiency.

Recently, reports focus on improving SNR of magneto-acoustic signal are reported. Zhang et al. proposed the single frequency continuous wave exciting method [13,14]. A continuous sinusoid wave is used to excite the magneto-acoustic signal. The sonic source can be located by measuring the amplitude and phase. A higher SNR and measuring accuracy can be achieved. However, the conductivity image is difficult to reconstruct based on single frequency continuous wave measurements. Aliroteh et al. studied frequency modulating and step-in frequency exciting method [15]. They used step frequency continuous wave as well as frequency-modulated continuous wave to increase the SNR. But the frequency modulating and step-in frequency method will make error in multi-frequency measurement due to the narrow band of the transducer.

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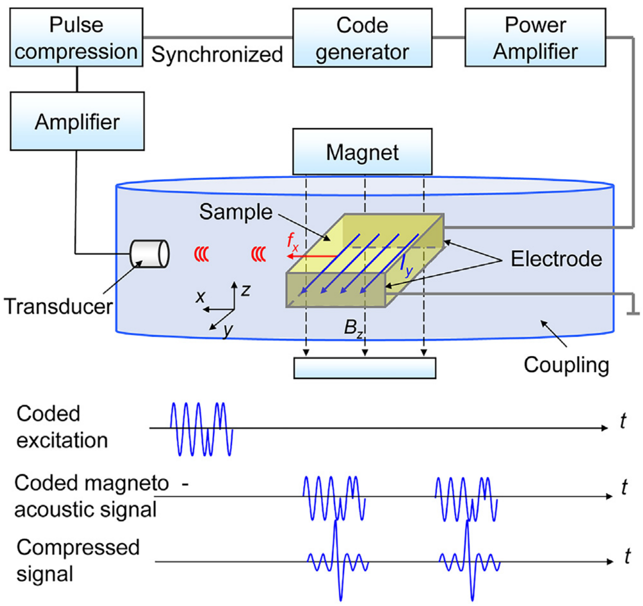

Fig. 1. Scheme of Magneto-acoustic imaging using coded excitation.

Emerson et al. studied differential frequency excitation using dual-frequency ultrasound to generate the Magneto-acousto-electrical tomography (MAET) signal at the difference frequency through the ultrasound radiation force mechanism [16]. The approach get the SNR increased, but the differential frequency excitation is limited by resolution. Therefore, new processing method need to be developed to improve SNR of magneto-acoustic signal and shorten the imaging time.

In this study, a coded excitation method is proposed for magneto-acoustic signal to improve the SNR. The long lasting exciting signal will increase the power of the magneto-acoustic signal. It will eventually increase the SNR. Because the frequency of the magneto-acoustic signal is the same as the excitation. It implies that the coded characteristics of the exciting signal will be reflected in magneto-acoustic signal which can be used for further compression. Therefore, the coded excitation method which is generally used in radar [17] and traditional ultrasonic [18] imaging is introduced in magneto-acoustic imaging.

2. Theory

Magneto-acoustic imaging method imposes excitation onto the sample, the Lorentz force causes the sample to vibrate and produces sonic wave. The sonic signal can then be measured outside the sample, as Fig. 1 shows. The sonic signal follows wave equation [19].

$$\nabla^2 p(\mathbf{r},t) - \frac{1}{c_s^2}\frac{\partial^2 p(\mathbf{r},t)}{\partial t^2} = \nabla\cdot[\boldsymbol{J}(\mathbf{r},t)\times\boldsymbol{B}_0(\mathbf{r})]\cdot\delta(t) \quad (1)$$

Wherein $p(\boldsymbol{r}, t)$ represents magneto-acoustic signal at position $\boldsymbol{r}$, $\boldsymbol{J}$ is current density in the sample, $\boldsymbol{B}_0$ is flux density of magnetic field. $\boldsymbol{r}$ is the location of the sonic source. c_s is sonic velocity in the sample, the value of c_s in water and most biological soft tissue is about 1500 m/s, $\delta(t)$ is delta pulse excitation.

According to Green equation, the magneto-acoustic signal can be solved as [19,20].

$$p(\mathbf{r},t) = \frac{-1}{4\pi}\int_V \mathrm{d}\mathbf{r}'\nabla_{\mathbf{r}'}\cdot[\sigma(\mathbf{r}')\mathbf{E}(\mathbf{r}')\times\mathbf{B}_0(\mathbf{r}')]\frac{\delta(t-R/c_s)}{R} \quad (2)$$

Table 1
Barker code with different bit lengths.

Bit length	Barker code
5	+++-+
7	+++–+-
11	+++—+–+-
13	+++++–++-+-+

Suppose the excitation is $s(t)$, the symbol * represents convolution operation. Eq. (2) can be modified as following:

$$p(\mathbf{r},t) = \frac{-1}{4\pi}\int_V \mathrm{d}\mathbf{r}'\nabla_{\mathbf{r}'}\cdot[\sigma(\mathbf{r}')\mathbf{E}(\mathbf{r}')\times\mathbf{B}_0(\mathbf{r}')]\frac{\delta(t-R/c_s)}{R} * s(t) \quad (3)$$

Where $\nabla_{\mathbf{r}'}\cdot[\sigma(\mathbf{r}')\mathbf{E}(\mathbf{r}')\times\mathbf{B}_0(\mathbf{r}')]$ is sonic source, σ is conductivity of the sample, $\boldsymbol{E}$ is electrical field. Lorentz force density is $\boldsymbol{f}=\sigma(\boldsymbol{r}')\boldsymbol{E}(\boldsymbol{r}')\times\boldsymbol{B}_0(\boldsymbol{r}')$. R is distance from $\boldsymbol{r}$ to transducer. Term $\delta(t-R/c_s)/R$ contains the time delay formed by sonic transmitting from sonic source to the transducer.

The scheme of Magneto-acoustic imaging using coded excitation is showed in Fig. 1. In this method, a code generator produces Barker code. It is amplified by power amplifier and then imposed by electrode to the sample, which is placed in magnetic field. Then the magneto-acoustic signal will produced by Lorentz force. The signal is detected by transducer and amplified by amplifier. Then the signal is processed by pulse compression.

Suppose the excitation $s(t)=e_1(t)$, the pulse response of transducer is $h(t)$, and $e_2(t)$ is the pulse response of the compressor. The processed signal $p_1(t)$ could be written as following:

$$p_1(t) = e_1(t) * p(\mathbf{r},t) * h(t) * e_2(t) \quad (4)$$

If the excitation and the compressor satisfy the condition (5),

$$e_1(t) * e_2(t) = \delta(t) \quad (5)$$

PutEq.(5)intoEq.(4).

$$p_1(t) = \delta(t) * p(\mathbf{r},t) * h(t) = p(\mathbf{r},t) * h(t) \quad (6)$$

Then the sonic signal from the sample can be obtained.

3. Method

3.1. Simulating method

Simulations are done to investigate the feasibility of the coded excitation method for magneto-acoustic imaging. As Fig. 1 shows, a rectangular sample is used. The size is 45 mm* 4 mm* 5 mm. The electrode is added at the left and right side surface of the sample, to make the exciting current flow along y axis. The simulations make the one-dimension transmitting approximation. That is to say, suppose the magnetic field is along the z axis, the sonic signal will transmit along the x axis. Thus the front and back boundaries of the sample can be measured and imaged.

Barker code [21] is adopted and the code width is 1 microsecond for imaging resolution of millimeter level. A series of Barker codes with 5bit, 7bit, 11bit and 13bit are applied to make a comparison to investigate the effect of SNR improvement. Barker codes with these bit lengths are demonstrated in Table 1.

The coded exciting signals of the codes above are simulated. The magneto-acoustic signals are computed using Eq. (2). Then, the coded magneto-acoustic signals are compressed using a self-adaptive matched filter [22]. The self-adaptive matched filter to Barker coding is achieved by reversing the code order of the temporal point spread function of excitation. Suppose the duration of the coded excitation is t_c, $e_2(t)=e_1(t_c-t)$.