3P5-4

Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 531-532
18-20 November, 2009

Pulse Compression Imaging Based on Split-and-Merge Strategy
分離合成方式によるパルス圧縮画像化法

Takuya Yamamura[1†], Masayuki Tanabe[2,3], Kan Okubo[2] and Norio Tagawa[2] ([1]Facult. System Design, Tokyo Metro. Univ.; [2]Graduate School of System Design, Tokyo Metro. Univ.; [3]JSPS Research Fellow)
山村拓也 [1‡], 田邉将之 [2,3], 大久保寛 [2], 田川憲男 [2] ([1] 首都大学東京 システムデザイン学部; [2] 首都大学東京大学院 システムデザイン研究科; [3] 日本学術振興会特別研究員 DC)

1. Introduction

Pulse compression technique (PCT) has been investigated for medical ultrasound imaging in the last decade[1-6]. PCT using frequency modulated (FM) linear chirp signals can provide higher signal-to-noise ratio (SNR) in medical ultrasound imaging. Higher SNR allows imaging of structures which are located far from a transducer and also allows to utilize higher frequencies.

SNR is proportional to the product *TB*, which is called the time-bandwidth product (TBP), where *T* is the duration time of transmitted chirp signal, and *B* is the bandwidth of it. Therefore, to obtain higher SNR using PCT, we should increase *T* because *B* is limited by the resonance characteristics of ultrasound transducer. However, due to the long duration time of chirp signal, to distinguish received signal from transmitted signal is difficult when transmitted signal and received signal are overlapped.

In this study, we propose a new method to avoid the occurrence of the above mentioned overlapping based on split-and-merge strategy. At first, by splitting the transmitted signal into *N* shots, we shorten the duration time per shot. The split signals are transmitted sequentially and received with a single transducer. This technique can realize near-field imaging with higher SNR.

2. Basic method

At first, let FM linear chirp signal express as:

$$s(t) = \cos\left[2\pi\left(f_s + B/(2T)t\right)t\right] \text{ for } 0 \le t \le T, \quad (1)$$

where f_s is the start frequency, *B* is the bandwidth and *T* is the duration time. Cross correlation function (CCF) using an echo signal $r(t)$ and a transmitted signal $s(t)$, is given as a function of the time lag τ:

$$\mathrm{CCF}(\tau) = \int_0^{\infty} r(t)s(t-\tau)dt . \quad (2)$$

After PCT, a half-width of CCF is 1/*B* μs and SNR is *TB* times larger than that of a single-carrier pulse with a Gaussian envelope. In the proposed method, the transmitted signal $s(t)$ is divided into *N* pieces and the resultant short pulses are transmitted sequentially for the purpose of near-field imaging. We synthesize all signals which are received sequentially.

Each transmitted signal $s_i(t)$ is expressed as:

$$s_i(t) = \cos\left[2\pi\left(f_i + \frac{f_B}{2T}t\right)t\right], \quad (3)$$

$$f_i = f_s + (f_B - \xi)(i-1), \quad (4)$$

$$\text{for } 0 \le t \le T, \quad i = 1,2,3,\cdots,N,$$

where f_i is the start frequency of i^{th} signal, f_B is the bandwidth of each short pulse and ξ is the overlapped bandwidth. $S_i(f)$ is a Fourier transform of $s_i(t)$ as shown in **Fig.1** (solid line). We obtain the synthesized signal using frequency components of each bandwidth, as shown in Fig.1 (bold line).

3. Experiments

Each experiment is conducted with three types (Type 1, Type 2 and Type 3) using a single transducer, which is located in water tank with a stainless steel block. The duration time for Type 1, Type 2 and Type 3, is *T* = 2 μs. **Table 1** shows the conditions of each transmitted signal.

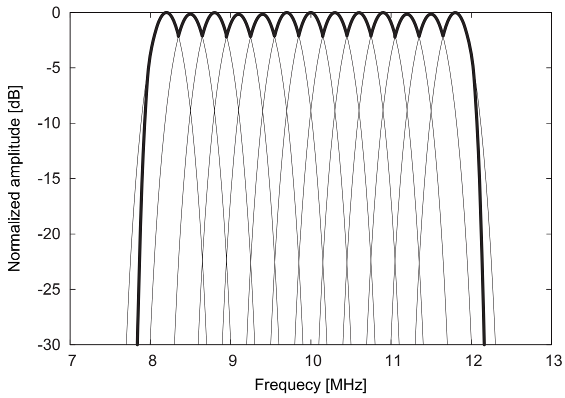

Fig. 1: Example of normalized amplitude of $S_i(f)$ (solid line) and synthesized signal (bold line), *T* =2 μs, *B* = 0.4 MHz, *N* =13, and ξ= 0.1 MHz.

E-mail : y.takuya1128@gmail.com

Table 1: Conditions of each transmitted signal

	T[μs]	B [MHz]	ξ [MHz]	N	TBP
Type 1	2	0.4	0.15	13	78
Type 2	2	0.4	-	1	0.8
Type 3	2	4	-	1	8

Type 1 consists of 13 pulses. The proposed method has been conducted on Type 1. The bandwidth is f_B = 0.4 MHz. The start frequency of each signal is calculated by Eq.4 respectively. For example, f_1 = 8 MHz, f_2 = 8.25 MHz, and so on. Expected TBP of synthesized signal of Type 1 is 78.

Type 2 consists of one signal, where the start frequency and the bandwidth are f_1 = 8 MHz and f_B = 0.4 MHz respectively; it is identical to $s_i(t)$ signal of Type 1. Expected TBP of Type 2 signal is 0.8.

Type 3 also consists of one signal, where the start frequency and the bandwidth are f_1 =8 MHz and f_B =4MHz respectively; the bandwidth is identical to synthesized signal of Type 1. Expected TBP of Type 3 signal is 8.

4. Results and discussion

Normalized amplitudes of received signals of Type 1 are shown in **Fig. 2** Envelopes of the compressed Type 1 signal (solid line) and the

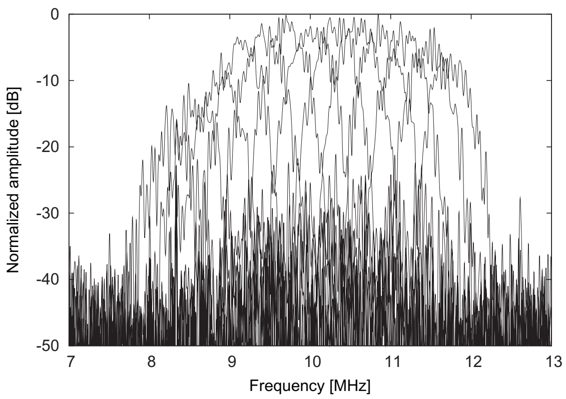

Fig. 2: Normalized amplitudes of received signals in Type 1

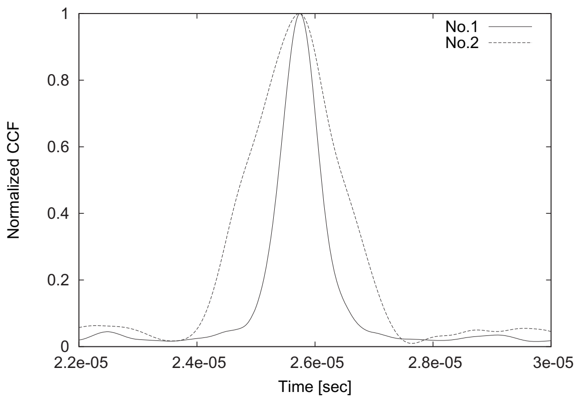

Fig. 3: Normalized CCF of Type 1(solid line) and Type 2 (broken line)

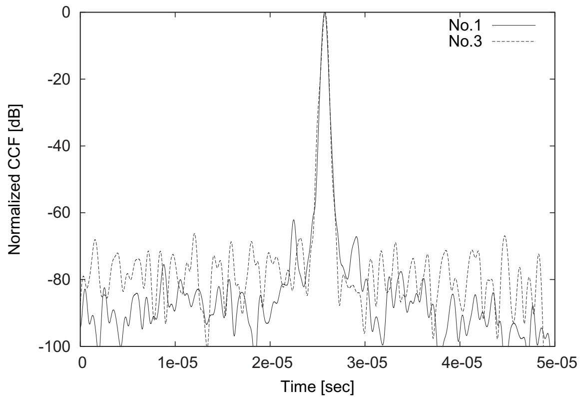

Fig. 4: Decibel representation of normalized CCF of Type 1 (solid line) and Type 3 (broken line).

compressed Type 2 signal (broken line) are shown in **Fig. 3**. This figure indicates that the half-width of Type 1 signal is approximately half of that of Type 2 signal. **Figure 4** is the decibel representation of envelopes of the compressed Type 1 signal (solid line) and the compressed Type 3 signal (broken line). Although both half-widths are almost same, noise level of Type 1 is 10 to 20 dB lower than that of Type 3.

5. Conclusion

In this study, we proposed a new method to avoid the overlapping of transmitted signal and received signal based on split-and-merge strategy. This technique can realize near-field imaging with higher SNR. The method was verified by experiments. The experiments show that the proposed method provides higher SNR.

This study assumes that the imaging target is static. If the imaging target has dynamic aspect, we can improve temporal resolution of imaging by effectively using periodicity of the motion, for example, respiration and heart beat, and it should be studied in future.

Acknowledgment

This work was supported by JSPS KAKENHI 21-8253.

References

1. T. Misaridis and J. A. Jensen: IEEE Trans. Ultrason. Ferroelectr. Freq. Control **52**, (2005) 177
2. Z. Hu, T. Moriya, and Y. Tanahashi: Jpn. J. Appl. Phys. **40** (2001) 3896
3. M.Tanabe, K. Okubo, and N. Tagawa : Jpn. J. Appl. Phys. **48** (2009) 07GK13
4. M.Tanabe, K. Okubo, N. Tagawa, T. Moriya : Jpn. J. Appl. Phys. **47** (2008) 4149
5. Y. Tonegawa, N. Tagawa, and T. Moriya: Jpn. J. Appl. Phys. **43** (2004) 3076
6. Z. Hu, N. Tagawa, and T. Moriya: Jpn. J. Appl. Phys. **39** (2000) 3233