Calculation of Pulse Fuze Signal's Ambiguity Function and Study of Its Parameters Extraction Based on DSP

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Abstract. This paper proposes a method of LFM pulse fuze signal's parameter extraction based on ambiguity function and implementation by DSP. Firstly, two-dimensional autocorrelation is done for the received signal, namely calculating the signal's ambiguity function, then according to the characteristic of fuze signal, the characteristic parameters is extracted on ambiguity function. The whole system is based on TMS320C6416 chip produced by TI company. The simulation result shows that the frequency modulation characteristic of signal can be detected effectively and parameters can be estimated accurately, the method which needs no prior information has good anti-noise ability. The test result verifies that the system competed has high reliability and real-time property.

Keywords: Fuze · LFM pulse train signal · Ambiguity function · Digital signal process

1 Introduction

The chirp fuze is to determine the distance between the source and the target by measuring the delay time between the transmitted signal and the target echo signal, due to it can solve the contradiction between the range resolution and the transmitted average power, and it retains the pulse signal high-range resolution and has been widely used in modern radio fuzes [1–3]. Many scholars at home and abroad have done a lot of work [4, 5]. Literature [4] proposes an algorithm for phase domain parameter estimation, but it needs to estimate the carrier frequency of the signal first, transform the intermediate frequency signal into a baseband signal, and then extract the parameters. The algorithm is more complicated. Literature [5] gives the theory and simulation analysis of LFM continuous wave signal modulation parameter extraction based on ambiguity function, but it does not analyze the chirp signal, nor does it analyze the feasibility of this method in practical applications. In recent years, electronic products have developed by leaps and bounds. TI's high-performance fixed-point DSP-TMS320C6416 [6, 7] has strong data processing capabilities and high computing speeds, which can meet the requirements of real-time processing of large amounts of data. This paper studies the problem of LFM burst fuze signal parameter extraction. Starting from the correlation domain, the extraction

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algorithm of its characteristic parameters is proposed based on the fuzzy map of the LFM burst signal, and the feasibility of its practical application is verified by implementing it on a high-speed DSP.

2 Principle of Pulse Fuze

The principle block diagram of the chirp pulse fuze is shown in Fig. 1 [8, 9]. The pulse generator forms narrow pulses to pulse modulate the chirp signal to generate the chirp pulse train signal, which is amplified by the radio frequency amplifier and radiated by the transmitting antenna. The echo signal is mixed with the local reference signal after being low-noise amplifier. The latter signal is processed by the signal processor to extract the time delay and Doppler information of the echo signal. Due to the special working environment of the fuze, its operating distance is relatively short, and the processing and warning time is short, which requires the signal processing equipment to have high calculation speed and strong processing capability.

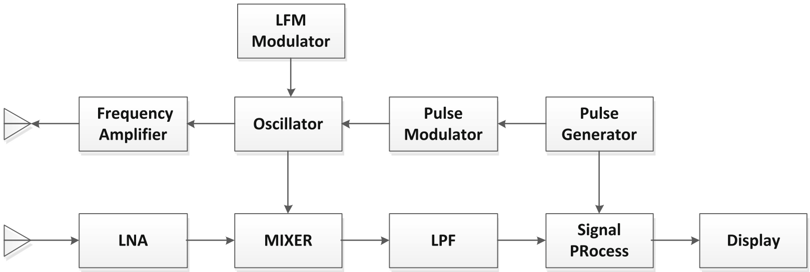


Fig. 1. Block diagram of LFM pulse train fuze system

3 Chirp Burst Signal and Its Ambiguity Function

3.1 Chirp Pulse Train Signal

The expression of the chirp burst signal is:

$$s(t) = \frac{A}{\sqrt{N}} \sum_{n=0}^{N-1} v(t - nT_r) \tag{1}$$

$v(t) = e^{j2\pi(f_0 + \frac{1}{2}kt)t}$ $t \leq t_p$, A is the amplitude of the transmitted signal, N is the number of sub-pulses, f_0 is carrier frequency of the signal, ΔF is modulation bandwidth, t_p is modulation period (Sub-pulse width), T_r is sub-pulse repetition period, k is the modulation slope of the signal, $k = \Delta F / t_p$。Observation formula (1) shows that the feature parameters of being extracted are ΔF, t_p,T_r and k。

3.2 Ambiguity Function of Chirp Burst Signal

In the theory of fuze signal analysis, ambiguity function is an important tool for analyzing and comparing the "optimization" degree of signal processing system. The definition of the fuzzy function is as follows [9]:

$$\chi(\tau, \xi) = \int_{-\infty}^{+\infty} u(t)u^*(t+\tau)e^{j2\pi\xi t}dt \tag{2}$$

According to the derivation [9], The ambiguity function of the chirp signal is:

$$\chi(\tau, \xi) = \frac{1}{N} \sum_{p=-(N-1)}^{N-1} \chi_1(\tau - pT_r, \xi)\left[e^{j\pi\xi(N-1-p)T_r} \cdot \frac{\sin \pi\xi(N-|p|)T_r}{\sin \pi\xi T_r}\right] \tag{3}$$

$$\left|\chi_1(\tau - pT_r, \xi)\right| = \begin{cases} \left|\dfrac{\sin\left[\pi\left(\xi - k\left|\tau - |p|T_r\right|\right)\left(t_p - \left|\tau - |p|T_r\right|\right)\right]}{\pi\left(\xi - k\left|\tau - |p|T_r\right|\right)}\right| & \left|\tau - |p|T_r\right| < t_p \\ 0 & \text{其他} \end{cases} \tag{4}$$

It can be seen that the ambiguity function of the chirp burst signal is composed of a series of different values p of the chirp sub-pulse ambiguity function $|\chi_1(\tau - pT_r, \xi)|$ on the delay axis τ, which is weighted by a factor $\frac{\sin \pi\xi(N-|p|)T_r}{N \sin \pi\xi T_r}$.

4 Algorithm for Extracting Characteristic Parameters of Chirp Burst Fuze Signal

After obtaining the ambiguity function for the intercepted LFM burst fuze signal, the characteristic parameters of the LFM burst fuze signal are extracted according to the result of the ambiguity function. For the convenience of discussion, first record the calculated ambiguity function data as $\tau_{1\times i}$ (time delay matrix), corresponding to the τ axes in the 3D fuzzy graph; $\xi_{1\times j}$ (frequency offset matrix), corresponding to the ξ axes in the 3D fuzzy graph; $\chi_{i\times j}$ (fuzzy function matrix) Corresponding to the vertical axis in the 3D blur graph, that is, the blur function value at position (τ_i, ξ_j) is $\chi_{i\times j}$. It can be seen from the analysis that the contour map of the ambiguity function of the LFM pulse train signal with N repetition periods is composed of $(2N-1)$ parallel lines, and the distance between any two adjacent parallel lines with the same frequency offset corresponding to the delay axis is Pulse repetition period T_r; half of the difference between the maximum frequency shift $\xi_{\max}$ and the minimum frequency shift $\xi_{\min}$ in the contour map is the modulation bandwidth ΔF; half of the delay axis distance corresponding to $\xi_{\max}$ and $\xi_{\min}$ is the modulation period (sub-pulse width) t_p. Therefore, the extraction steps of the characteristic parameters of the LFM burst signal are as follows:

(1) Extraction of pulse repetition period T_r.

Step1: For each frequency offset ξ_n, Obtain the respective delay vectors corresponding to the peaks of the slice of $\chi_{i\times n}$, denoted as $\{\tau_1, \tau_2, \tau_3, \cdots\}$;
Step2: Calculate the difference between adjacent delays and get the interval vector of adjacent delays $\Delta\tau = \{\Delta\tau_1, \Delta\tau_2, \Delta\tau_3 \cdots\}$, $(\Delta\tau_i = |\tau_{i+1} - \tau_i|)$。
Step3: Searched delay interval vector $\Delta\tau$, Calculate the average value $\Delta\tau_{mean}$ of $\Delta\tau_i$, you can estimate that the pulse repetition period T_r is $\hat{T}_r = \Delta\tau_{mean}$.

(2) Extraction of modulation bandwidth ΔF and modulation period t_p.

Step1: Search the frequency shift axis in the 2D ambiguity graph to find $\xi_{\max}$ and $\xi_{\min}$ and their corresponding delays $\tau_{\max}$ and $\tau_{\min}$.
Step2: Calculate their difference $\Delta\xi = \xi_{\max} - \xi_{\min}$,$\Delta\tau = \tau_{\max} - \tau_{\min}$. From the above analysis, it can be estimated that the modulation bandwidth ΔF of the signal is $\Delta\hat{F} = \Delta\xi/2$, and the modulation period t_p is $\hat{t}_p = \Delta\tau/2$.

(3) Extraction of FM slope k.
According to the modulation period t_p and modulation bandwidth ΔF extracted above, the frequency modulation slope k can be directly estimated as $\hat{k} = \Delta\hat{F}/\hat{t}_p$. Since both $\Delta\hat{F}$ and $\hat{t}_p$ are estimated by the algorithm, it is inevitable that they are not accurate enough. If the modulation slope $\hat{k}$ is directly estimated from the above formula, it may be even more inaccurate. Here, you can directly search for the point on the oblique knife edge in the fuzzy picture of the LFM pulse train signal, and use the least square method to directly estimate the modulation slope $\hat{k}$.

5 Realization of Ambiguity Function of LFM Burst Fuze Signal Based on DSP

As shown in Fig. 2, the system hardware uses the TMS320C6416 DSP chip produced by TI as the digital signal processor. The system uses the Virtex-II Pro FPGA produced by Xilinx to generate two orthogonal chirp train signals, then pack the data, and transmit the data to the DSP through the EMIFA bus for signal processing. Due to the large amount of data that needs to be processed, an off-chip SDRAM needs to be used as a cache.

5.1 The Performance Characteristics of TMS320C6416 DSP

TMS320C6416 DSP is a high-performance fixed-point DSP launched by TI. Its clock frequency is up to, the highest processing capacity is, and 8 instructions can be executed per clock cycle. It uses the unique VelociTI structure of TI, which is a CPU with an

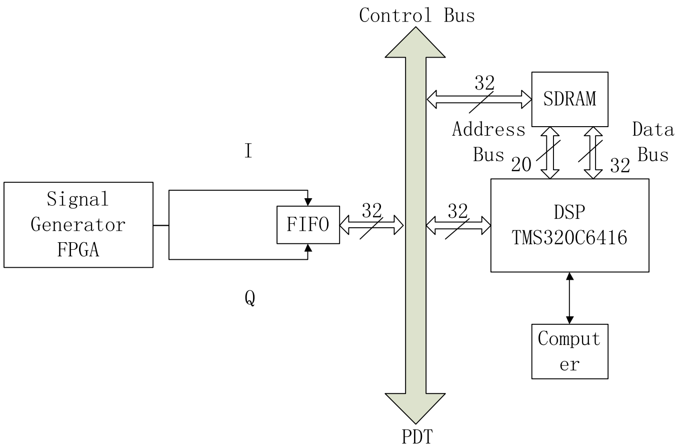


Fig. 2. Hardware structure of the system

improved Harvard structure and super long instruction word. This structure makes it exceed the performance of traditional superscalar CPUs. It contains 64 Kb on-chip data memory, which can be configured as a program memory in cache mode. In addition, the uniformly addressed 2 GB off-chip address space provides effective support for all memory types, with non-sticky memory interfaces and various DRAM refresh logic. This system uses two SDRAMs with a total capacity of 64 MB.

5.2 Procedure Flow

The flow chart of the realization of the LFM burst ambiguity function is shown in Fig. 3. In the calculation process, each frequency shift needs to be cross-correlated once, and the amount of calculation data is very large. TMS320C6416 provides 8 arithmetic units that can be operated at the same time, which can complete the multiplication of two 32-bit numbers at the same time, which is of great significance for a large number of butterfly operations in FFT/IFFT in this system. In this system, FFT/IFFT uses TI library functions DSP_fft32 × 32 and DSP_ifft32 × 32. When the library function is used, 1101196 clock cycles are required for each 1024-point cross-correlation operation [10]. This article intends to perform 100 cross-correlation to obtain the ambiguity function. Since the DSP clock frequency can be reached 600 MHz, the ambiguity function is completed. The calculation only needs 0.183 s, and the real-time performance is high. With the rapid development of electronic devices and continuous optimization of software algorithms, real-time performance will be further improved.

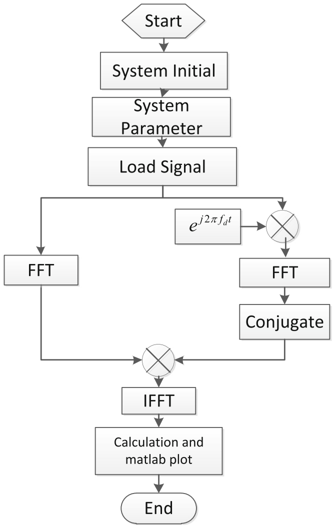


Fig. 3. Flow chart of the realization of LFM pulse train ambiguity function

6 Experimental Result

6.1 Chirp Signal Generation

Generate the target echo signal of the LFM burst fuze through FPGA simulation, set the signal carrier frequency (ie intermediate frequency) $f_0 = 5.5\,MHz$, modulation bandwidth $\Delta F = 1\,MHz$, modulation period $t_p = 10\,\mu s$, Pulse repetition period $T_r = 100\,\mu s$, pulse repetition period $N = 4$, the number of sub-pulses for signal processing E, The signal is shown in Fig. 4.

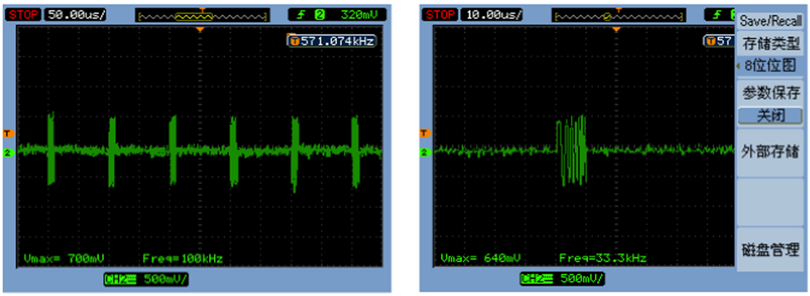
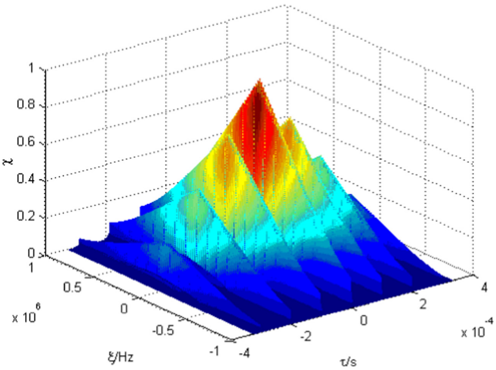


Fig. 4. The diagram of the LFM pulse train signal designed

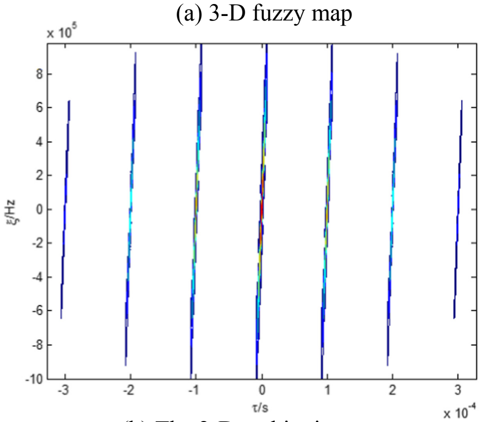
6.2 Implementation of Ambiguity Function of Linear Frequency Modulation Burst Signal on DSP

The LFM pulse train signal generated above is transmitted to the DSP through the PDT transmission mode. After the DSP receives the signal, it calculates the ambiguity function of the signal. The result of the calculation is shown in Fig. 5, which is a fuzzy map without adding noise.

According to Sect. 3, by searching for the maximum frequency shift $\xi_{\max}$ and minimum frequency shift $\xi_{\min}$ in the 2-D ambiguity graph and their corresponding time delays $\tau_{\max}$ and $\tau_{\min}$, half of the frequency shift difference is the modulation bandwidth $\Delta F = 1\,MHz$ of the signal, corresponding to Half of the delay difference is the modulation period $t_p = 10\,\mu\text{s}$ of the signal. Search for the delay vector corresponding to the peak of each frequency shift slice, find the delay interval of adjacent delays and take the average value to obtain the pulse repetition period $T_r = 100\,\mu\text{s}$.



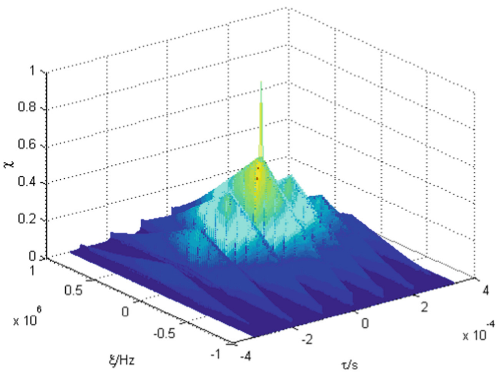
(a) 3-D fuzzy map



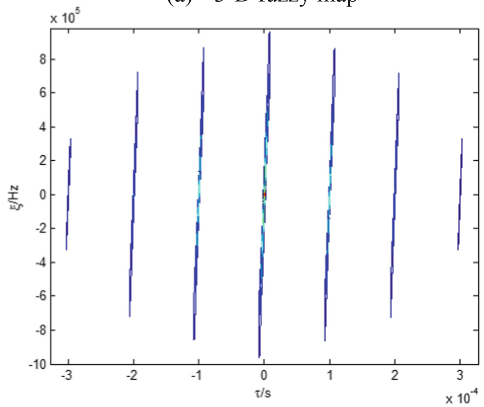
(b) The 2-D ambiguity map corresponding to (a)

Fig. 5. Ambiguity graph of LFM pulse train signal calculated by DSP ($N = 4$)

When the signal-to-noise ratio is $SNR = 0\,dB$, the ambiguity function diagram of the signal is shown in Fig. 6. It can be seen from the figure that when the signal-to-noise ratio is $SNR = 0\,dB$, its modulation parameters can still be extracted very accurately.



(a) 3-D fuzzy map



(b) The 2-D ambiguity map corresponding to (a)

Fig. 6. Ambiguity graph of LFM pulse train signal calculated by DSP when $SNR = 0\,\text{dB}$

6.3 Parameter Estimation and Analysis

According to the method of identifying the characteristic parameters of the LFM burst signal introduced above, that the anti-noise performance of using the fuzzy function to extract the modulation parameters of the LFM burst fuze signal is very good. Because the cross-correlation function of the LFM burst fuze signal is concentrated at a specific frequency shift, and the Gaussian white noise does not have this rule, its ambiguity function is "pushpin", and it cannot effectively interfere with the characteristic parameters of the LFM burst fuze signal. Extraction. In addition, the anti-noise performance can be enhanced by appropriately increasing the amplitude of the LFM burst signal.

7 Conclusion

This paper describes an algorithm for realizing the ambiguity function of LFM burst fuze signal based on high-speed fixed-point DSP, and extracts the modulation parameters of the signal according to the ambiguity function theory. This method first performs a two-dimensional autocorrelation transformation on the intercepted or received LFM burst fuze signal, that is, calculates the ambiguity function of the signal, and then combines the characteristics of the LFM burst signal itself to extract the modulation period, modulation bandwidth, and pulse in the correlation domain. Modulation parameters such as repetition period. The experimental results show that the method has high parameter estimation accuracy and strong anti-noise performance without any prior information.

Due to the excellent performance of TMS320C6416 DSP in real-time signal processing with large data volume, the method of extracting characteristic parameters by fuzzy function can be realized. The experimental results show that the system has high reliability and real-time performance, which has certain reference value for the design of fuze jammers.

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