Principle and Performance Analysis of Truncation Pulse Compression in the Decrease of the Radar Blind Zone

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Abstract. In order to improve the range resolution and detection distance of the radar, the method called pulse compression (PC) is commonly used, which not only ensures enough signal energy for the remote detection, but also makes the time-bandwidth products much greater than 1. But if time-width of the pulse signal is increased, as a result the blind zone is also increased inevitably. To solve the issue, we proposed a method named truncation pulse compression, and its principle and performance are analyzed in the paper. This novel method is different from those traditional methods is that it transmits short pulse to reduce blind zone and then combine modulated pulses. It can not only decrease the blind zone, but also can reduce the complexity of radar system. We have performed some simulation experiments to verify the principle of this method, and the simulation results showed that the truncated compressed pulse can effectively solve the problem of the increase of blind zone caused by the pulse compression and reduce the radar system complexity.

Introduction

As an important modern radar technology, pulse compression technology [1-2] can effectively solve the contradictions of detection range and range resolution of the traditional radar system, which is widely employed in ultra-wideband (UWB) radar [3] and Doppler weather radar [4-6]. Linear frequency modulation (LFM) signal [7] is widely used for pulse compression signal [8-13], and it has the characteristics of large time width and large bandwidth that can assure enough energy for radar system to detect the remote target with high range resolution. However, detection blind zone will be enlarged when the pulse width of the pulse compression signal is increased [14].

It is well known that the detection blind range of the single base station radar system is proportional to the time-duration of the transmitted radar signal, and transmitting additional short pulse is commonly employed to decrease detection blind zone [14]. Recently, some researchers [15] proposed a method which combined one short modulated pulse and one long modulated pulse to solve this problem. Although this method can ensure large detection range and high range resolution, this method has its problem. The first problem is how to choose the time width and time interval of the two pulses, and the second problem is the mutual interference of the two pulses. The final problem, also the most serious one, is that the combined pulse needs radar system to generate and transmit different modulated pulses, and the radar receiver must receives the echo of the short pulse and the long pulse respectively, which can greatly increase the complexity of the single base station radar system. To solve the above problem, a truncation pulse compression method is presented in this paper. The truncation pulse compression can greatly finish the function of combined pulse. And the application analysis of this method using in the radar detection has been made in this paper. The second section described the model of the combined pulses and elaborated the method that how the
combined pulses decreased the blind zone. Section III introduced the fundamental principle of the truncation pulse compression and the conditions of decreasing the blind zone, and elaborated the realization of the proposed method in the single radar base station system. Section IV was the simulation of the above principle, and the simulation results showed the feasibility of the truncation compression pulses decreasing the radar detection blind zone. Section V was the results and conclusion of the paper.

**Combined Pulse Model**

For the general pulse with a time-duration of T, the time-bandwidth product BT approximates the number of 1, which will be much greater than 1 after processed by pulse compression technique. In this case, the compression ratio D can be expressed as EQ (1):

\[
D = \frac{T}{\tau} = \frac{T}{1/B} = TB
\]

Where T is the width of input pulse signal of matched filter, and \( \tau \) is the width of output pulse signal of matched filter. T is the modulated bandwidth. The compression ratio D is one of the main factors of the pulse compression processing.

The combined pulse was to combine two pulses with different time-duration modulated in different compression ratio, was proposed to decease the radar detection blind zone. Moreover, it can ensure those pulses with the same bandwidth which ensure the short pulses remained the same high range resolution with the long pulses. The waveform of combined bi-phase coded pulse is shown in Fig.1.

![Combined bi-phase coded pulse waveform.](image)

Assuming that the pulse width of short pulse was \( T_1 \) and the pulse width of long pulse was \( T_2 \), and their modulation bandwidths were \( B \). Then, the compression ratios can be represented respectively as the following equations:

\[
D_1 = T_1 \times B
\]

\[
D_2 = T_2 \times B
\]

Where \( D_1 \) and \( D_2 \) are the compression ratios of short pulse and long pulse respectively. And the distance of the detection blind zone which depends on the time-duration of the short pulse can be calculated by the equation (4),

\[
R_{\text{min}} = cT_1/2
\]

Where \( c \) is the light speed in the vacuum? The average power of the radar is magnified and the
maximum detection range increased to the four times square root of the compression ratio $D$ of the original detection range though the pulse compression technique. Hence, in order to ensure the continuity of combined pulse detection space, the maximum detection distance of the short pulse should be larger than the minimum detection distance of the long pulse. The relationship can be described by the following equation (5):

$$\sqrt[4]{D_1} \cdot R_{\text{max}} \geq R_{\text{min}}$$

Where $R_{\text{max}}$ is the maximum detection distance of the uncompressed short pulses, and $R_{\text{min}}$ is the minimum detection distance.

In this method, the detection blind zone can be decreased, but the different length codes were needed to modulate the short pulse and the long pulse respectively, which required two modulators in the radar transmission system and greatly increased the complexity of the single base station radar system.

**Truncation Pulse Compression Method**

In this section, truncation pulse compression model distinguished from the previous model is presented. It can not only have the function of combined pulses, but also can decrease the complexity of the single base station radar system.

For linear frequency modulation, truncation pulse compression signal can be described in the following equation (6):

$$S_i(t) = (\text{rect}(\frac{t}{T_i}) + \text{rect}(\frac{t}{T_e - T_i})) \cdot \cos(2\pi f_0 + \pi \frac{B}{T_e} t^2)$$

Where $\text{rect}(\frac{t}{T_i}) = 1 \quad (t \leq T_i)$, $\text{rect}(\frac{t}{T_e - T_i}) = 1 \quad (T_e - T_i \leq t \leq T_i)$, $T_i$ is the time-duration of the short pulse, $T_2$ is the time-duration of the long pulse, $T_e$ is the time-duration of the whole signal, $f_0$ is the center frequency, and $B$ is the modulation bandwidth. Fig. 2 shows that the time domain waveform of linear frequency modulation signal and the truncation pulse compression signal.
It can be seen in the equation (6) that truncation pulse compression signal is consist of a short pulse and a long pulse which are modulated by the same modulation rate $B/T_c$. In this signal, the short pulse is used to detect the targets of the short distance, and the long pulse is used to detect the targets of the long distance. Although the range resolution of this signal is inferior to that of the combined pulses, this method can decrease the blind zone of the combined pulses in the condition of the long detection range. In the transmitter of the single base station radar system, the truncation pulse compression signal can be generated by controlling the output time of the pulse generator or that of the transmitted antenna, which can overcome the disadvantages which combined pulse needs two different modulators, and can simplify the systematic complexity of the radar system.

Generally, the blind zone of the radar system depends on the time-duration of the transmitted signal. Therefore, no matter that transmitted signal is the truncation pulse compression signal or the combined pulses, the receiver of the radar system must receive the echo signal of the short pulse to detect the near targets before the long pulse is transmitted, and the time-duration and the time interval of the short pulse and the long pulse should meet the conditions which are described by equation (7), (8) and (9),

$$\frac{4}{\sqrt{D_1}} \cdot R_{max1} \geq R_{min2}$$ \hspace{1cm} (7)

$$c(T_2 - T_1)/2 \geq R_{min2}$$ \hspace{1cm} (8)

$$D_1 \geq 1$$ \hspace{1cm} (9)

Where $D_1 = B \cdot T_1^2/T_c$ is the compression ratio of the short pulse, $R_{min2} = c \cdot T_2/2$ is the blind zone of the long pulse, $T_1$ and $T_2$ are the time-duration of the short pulse and the long pulse respectively, and $c$ is the speed of light in the vacuum. In the case of the enough transmitted power, truncation compression pulse can decease the blind zone and ensure the larger detection distance when the radar system meet the conditions of equation (7), (8) and (9). And the blind zone is expressed by $c \cdot T_2/2$.

In order to detect the near targets, the truncation time of the matched filter of the radar receiver must be synchronous with that of the transmitter. Besides, some targets with the special positions can be detected by not only the short pulse but also the long pulse, where the echo of the short pulse might disturb the long pulse detection. In fact, the correlation of the short pulse and the long pulse which are modulated by the truncation pulse compression signal will be limited to a certain value.
Moreover, the interference will be reduced with the increase of width ratio of the short pulse and the long pulse. Fig. 3 shows the correlation waveform of four different ratios.

![Waveform Diagrams](image)

**Figure 3. The relation between the correlation output and width ratio.**

From Fig. 3, we can see that the correlation output decreases with the increase of the width ratio, and the simulation experiment results verify that when the long pulse is detecting the targets, the influence of the echo of the short pulse is extremely feeble in condition that the time width ratio is greater than 40.

**Simulation Results and Analysis**

According to the conditions which are proposed in the section III, the simulation experiment will be performed using the following parameters: modulation bandwidth $B$ is 1GHz, the time-duration $T_e$ of the whole pulse is 100 $\mu$s, the time-duration $T_i$ of the short pulse is 1 $\mu$s, the time-duration $T_i$ of the short pulse is 48 $\mu$s, the three different targets ranges are 200m, 7.5km, and 9km respectively, and the signal to noise ratio (SNR) of the three different targets are all 10dB. Assuming that the target in 200m might only be detected by the short pulse, the target in 9 km can only be detected by the long pulse, and the target in 7.5km can be detected by both the short pulse and the long pulse.

The whole echo of the hybrid waveform of the truncation pulse compression signal when it detects three different targets is shown in Fig. 4. It can be seen that the echo of the long pulse remains the characteristics of the echo of the linear frequency modulation, which is the hybrid echo of multi-targets. Thus, the proposed method can detect different multiple targets.
Figure 4. The hybrid waveform of whole truncation pulse compression echo and noise.

Figure 5. The compression output of detection three targets, the output gain of the target in 200m is 47.2dB, the output gain of the target in 7.5km is 85.64dB, and the output gain of the target in 9km is 85.44dB.

Fig. 5 shows the compression output through the truncation matched filter. The three wave crest represents the position information and the output gain of the three targets. During the process of the radar detection, the radar received the short pulse at first and the blind zone is depended on the time-duration of the short pulse. Generally, the blind zone can be calculated using the whole transmitted signal. In this simulation experiment, the time-duration of the whole pulse $T_r$ which is 100 $\mu$s can generate the blind zone of $c \cdot T_r / 2 = 15$km, but the blind zone in the above proposed method can be decreased to $c \cdot T_i / 2 = 150$m, which is 100 times less than the traditional blind zone, and the decrease rate is equal to the duty cycle of the short pulse in whole pulse. In Fig. 5, it is
shown that the target in 200m can be detected by the short pulse. Therefore, the proposed method in this paper can decrease the blind zone when using the pulse compression method. Besides, Fig. 5 also shows that the output gain of the two targets in 7.5km and 9km are 85.64dB and 85.44dB respectively, which the difference is only 0.2dB. And this can verify that the interference of the short pulse echo on the long pulse detection can be negligible when the width ratio the long pulse and the short pulse is larger.

Conclusion

In this paper, a method which is similar to the combined pulse is presented to solve the issue of the increase of detection blind zone in the pulse compression radar system. This method used the principle which transmitted the short pulse to reduce detection blind zone. The essence of the truncation pulse compression is that truncating the linear frequency modulation signal in the pulse compression technique, which has less complexity than the combined pulse method in the single base station radar system. This paper elaborates on the generation of the truncation pulse compression and the performance of this method in radar system. Simulation experiment results show the feasibility of the truncation pulse compression in detecting near targets and the truncation pulse compression can also decrease the blind zone from 15km to 200m.

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