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Detection of Advanced Pulse Compression Noise Based on FRFT

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Abstract:

Advanced Pulse Compression noise is a kind of signal with the advantages of linear frequency modulation signal and noise signal. In this paper, time-frequency analysis method based on fractional Fourier transform is used for the detection of APCN signal. Also, we derive the detection principle of this method in detail. The proposed method using time-frequency conversion provides better detection performance than previous methods for the detection of APCN signal. In addition, choosing appropriate signal parameters can make APCN signal obtain a large time-bandwidth product and provide low detection performance. Simulation results are presented to verify the theoretical prediction.

Model & Algorithm:

The discrete-time form of APCN signal:

$$v(n) = s(n) \circ g(n) = a_n e^{j(\pi\mu n^2 + \theta_n)}$$

where the amplitude a_n has a Rayleigh distribution with parameter 1 and satisfies $a_n \sim |R_1| \in [\alpha, 1]$, α is the amplitude factor and satisfies $0 \le \alpha \le 1$, the phase θ_n has a uniform distribution and satisfies $\theta_n \sim u(0, 2\pi) \in [0, 2\pi\kappa]$, κ is the phase factor and satisfies $0 \le \kappa \le 1$.

The FRFT of APCN signal:

$$\begin{aligned} X_p(u) &= \int_{-\infty}^{+\infty} K_p(u,t) x(t) dt \\ &= \int_{-\infty}^{+\infty} B_\beta e^{j\pi(u^2\cot\beta - 2ut\csc\beta + t^2\cot\beta)} a e^{j(\pi\mu t^2 + \theta)} dt \\ &= B_\beta \int_{-\infty}^{+\infty} e^{j\pi u^2\cot\beta - j\pi 2ut\csc\beta + j\pi t^2\cot\beta} a e^{j(\pi\mu t^2 + \theta)} dt \\ &= B_\beta e^{j\pi u^2\cot\beta} a e^{j\theta} \int_{-\infty}^{+\infty} e^{j\pi t^2(\cot\beta + \mu)} e^{-j2\pi t u\csc\beta} dt \end{aligned}$$

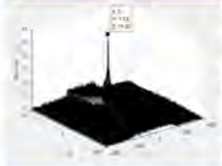
The discrete FRFT of APCN signal satisfies:

$$\beta = -\operatorname{arccot}\tilde{\mu} \text{ 、 } p = -2\operatorname{arccot}(\tilde{\mu})/pi$$

Where p is the order of FRFT, $p = 2\beta/\pi$, $B_\beta = \sqrt{1 - j\cot\beta}$, β can be seen as the counterclockwise rotation angle of the time-frequency plane around the origin, $\tilde{\mu}$ is the normalized frequency modulation slope.

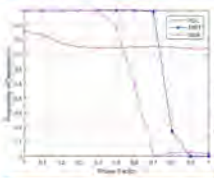
Results & Analysis:

Three-dimensional spectral distribution of APCN FRFT:



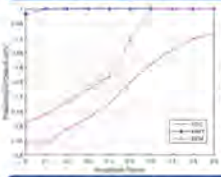
It shows that APCN signal under the above conditions has good energy aggregation characteristics in the FRFT domain when $p = 1.13$. The detection of APCN signal can be effectively completed by selecting an appropriate threshold to discriminate spectral peaks.

Detection probability versus phase factor:



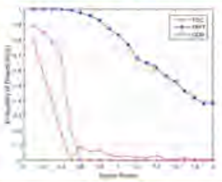
FRFT can guarantee 100% detection probability when $\kappa \le 0.7$, that is, the change of APCN signal phase has little effect on the energy aggregation of the signal on the optimal order. Therefore, FRFT provides the best detection performance when $\kappa \le 0.7$.

Detection probability versus amplitude factor:



It is obvious that the detection probability of FRFT is hardly affected by α and the detection probability of TOC and DCM increases with the increase of α. Thus, the detection probability of FRFT is superior to the other two when noise power and κ are fixed.

Detection probability versus noise power:



FRFT still reaches 80% detection probability when the noise power is 1, while the other two provide poor detection performance when the noise power is greater than 0.5.

Conclusion:

This paper proposes a detection method based on FRFT time-frequency analysis method for APCN signal detection. By exploiting the energy aggregation characteristics of APCN signal in FRFT transform domain, the APCN signal detection is effectively implemented. According to the simulation results of FRFT, DCM and TOC, FRFT has the best detection performance compared with the other two methods when noise power changes, which detects the spectral peak at the optimal order. In addition, the larger the amplitude factor or the smaller the phase factor of the APCN signal, the greater the difficulty of the APCN signal detection.

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