Intelligent ECCM technology via cognition and agility for the airborne radar

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Abstract: The electronic counter countermeasures (ECCM) technology is crucial to the modern airborne radar. In this study, opposed to the intelligent electronic countermeasure system, an intelligent anti-jamming technology is developed, which adjusts the working parameters and ECCM steps in real time and optimises the radar performance in various jamming scenarios. The framework of the proposed intelligent anti-jamming technology includes the cognitive jamming detection and suppression, adaptive frequency agility, and waveform diversity. The application of the proposed technology in the airborne radar is analysed via numerical simulations.

1 Introduction

As an important detection device, the airborne radar is always attacked by jammers in the modern war. So, it is important and necessary to have an excellent anti-jamming performance for the airborne radar, which can resist jammers to detect various kinds of targets correctly and intelligently. However, as the development of the electronic science and technology, the electronic war (EW) techniques have developed fantastically. Especially, with the emergence of various electronic countermeasure (ECM) techniques, tactics, and equipment, the battlefield of the modern airborne radar is becoming complicated and worsened. Jammers cannot be fully detected and discriminated by the conventional radar electronic countermeasure (ECCM) methods [1, 2]. Thus, new theories and methods are urgently applied to the radar ECCM design to improve the fighting efficiency of the airborne radar in a complex electro-magnetic environment [3, 4], which provides a direction for the future design of radar anti-jamming.

Just as it is successfully applied in many other fields, the intelligent technology including the neural network, the pattern recognition, and the genetic algorithms etc. are used to improve the ECCM performance of the airborne radar [5–7]. The combination of the pattern recognition with the neural network is an intelligent pattern recognition technology, which is worth more discussions of its application in radar ECCM. It mainly includes how to extract the features of the target and the interference, design a classifier to accomplish classification, and realise radar ECCM. Genetic algorithm is a type of randomly searching algorithm based on the natural selection and natural inheriting mechanisms in the biosphere. As for the ECCM application, it is mainly used together with the neural network to optimise the latter so as to improve the performance of ECCM. It can be predicted that a good combination and an integrated application of such intelligent methods as the neural network, pattern identifying, genetic algorithm, and fuzzy theory will further improve the performance of radar ECCM.

In this paper, an intelligent anti-jamming technology based on a dynamic closed-loop feedback system is introduced, which focuses on precise interference cognition and adaptively transmits to optimise the transmitter and receiver jointly. The proposed technology can increase the survival ability of the airborne radar in the complex electromagnetic environment.

Section 2 presents the research of intelligent anti-jamming technology for the airborne radar, where the scheme of intelligent anti-jamming and the key techniques are discussed, and then the performances of key techniques are shown in Section 3. Finally, conclusions are made in Section 4.

2 Intelligent anti-jamming technology

2.1 Scheme of intelligent anti-jamming technology

A traditional airborne radar has very little provision for ‘learning’ over time, feedback to the transmitter, or the integration of exogenous environmental information sources that can provide significant benefits. In this paper, the schematic diagram of the intelligent anti-jamming technology is shown in Fig. 1.

In contrast, the intelligent anti-jamming radar exhibits several advanced elements that could be argued to lead to better ECCM performance:

- ‘Knowledge’ of the environment and/or targets and jamming of interest: based on observed environmental/echo signals, transmit tactics and ECCM processing algorithms would be modified without delay.
- Adaptive transmit capability: true adaptive transmit involving the continuous signal, parameter variation, and optimum ECCM waveform techniques can be used to optimally reapportion the RF spectrum to maximise the signal-to-interference-plus-noise ratio.

2.2 Precise jamming cognition

In the pulse Doppler radar, the linear frequency modulation (LFM) and the phase-code pulse waveforms are convectional signals, and the smeared spectrum (SMSP) and chopping and interleaving jamming [8] are particularly proposed to counter the pulse compression radar, which produces a large number of false targets to destroy the detection function of the radar. It is essential to cognitive these jamming for the ECCM algorithm.

The time–frequency analysis tools provide a function which can describe the energy density of the signal in time and frequency-domain concurrently. This function can reflect the distribution of energy at a certain time and frequency. Therefore, the time–frequency analysis tools are used for the analysis of time-varying
signals in general, and the fractional Fourier transform (FrFT) is one of the most valid tools for the analysis of non-stationary time-varying signals [9].

The FrFT $F^p$ of order $p \in \mathbb{R}$ is a linear integral operator that maps a given function (signal) $f(t)$, $t \in \mathbb{R}$, $\mu \in \mathbb{R}$, which can be depicted as

$$F^p f(u) = \int_{-\infty}^{\infty} f(t) K_p(\mu, t) dt$$

(1)

where the kernel is defined as follows:

$$K_p(\mu, t) = \begin{cases} \frac{\exp(-ip\mu \sin(\alpha)/4 + ja/2)}{|\sin(a/2)|} & \alpha \neq np \\ \delta(\mu - t) & \alpha = 2np \\ \delta(\mu + t) & \alpha = (2n + 1)p \end{cases}$$

(2)

with

$$A_0 = \exp(-ip\mu \sin(\alpha)/4 + ja/2)$$

(3)

The chirp rate $\dot{k}$ and original frequency $\dot{f}_0$ can be estimated by the position of the peak value $(p, \mu)$ as follows:

$$\dot{k} = -\cot(p/2\pi)$$

(4)

$$\dot{f}_0 = \mu \csc(p/2\pi)$$

(5)

### 2.3 Coherent method for knowledge-aided frequency agility

In the pulse Doppler radar system, the frequency agility is usually performed between the batches of pulse, because the frequency change must wait for the coherent integration. The integration and processing give the ECM equipment enough time to measure the waveform parameters, and to generate and transmit the accurate jamming signal, which makes the jamming highly effective.

In this paper, basing on the frequency data obtained by precise interference cognition, the carrier frequency is changed adaptively from pulse to pulse, which prevents the ECM equipment from executing accurate jamming and reduces the effect of the jamming.

Assuming that the bandwidth of the baseband signal is $\Delta f$, the frequency agility sequence of the kth pulse is $b_k$, and the signal sample frequency is $f_s = \Delta f$, the signal of the kth pulse can be written as

$$s_k(t) = e^{j2\pi f_s t} e^{j2\pi f_s (t-t_0)} e^{2\pi j q_k t - \phi_k(t - t_0) / \tau}$$

(6)

where $q_k = b_k \Delta f$, $t_k \leq t \leq t_k + \tau$, and $\tau$ represents the signal pulse duration, $t_k = (k-1)T_0$, $T_0$ is the pulse repeat interval (PRI), and $\phi_k(t)$ is the modulation mode of the kth pulse.

The ith sample of the kth pulse can be expressed as

$$\bar{R}[k, i] \approx A[i] e^{-j2\pi(c-v)\tau_k / T_0} e^{-j2\pi(c-v)\Delta_k / c} e^{2\pi j п v_k} p_k / 2$$

(7)

where $p_k = (2\nu/c - v) \nu_k$, $\Delta_k = 2L_0(c + \nu)$, $c = 3 \times 10^8 m/s$, $\nu$ and $L_0$ are the velocity and range of the target, respectively. The coherence could not be realised by traditional FFT processing, as shown in Fig. 2a, because of the Doppler frequency $p_k$ caused by frequency agility.

Based on the range information of the target, the scale-transform discrete Fourier transform (ST-DFT) algorithm is adopted to solve the problem, and the result of coherent can be written as

$$\bar{R}(f) = \sum_{k=1}^{K} \bar{R}[k, i] e^{j2\pi(c-v)\nu_k \Delta_k / c} e^{-j2\pi f_0 \nu_k / c} e^{2\pi j п f_k} p_k / 2$$

(8)

When $(2\nu)/(c-v)T_0 - (f/f_0) = 0$, the maximum of (8) will be obtained.

### 2.4 Anti-jamming technology based on waveform diversity

The digital radio frequency memory (DRFM) repeating jammer utilises the captured pulses of the previous PRIs to produce multiple false targets; the generating scheme of the jamming signal is shown in Fig. 3, and then the waveform-diversity method is proposed to deal with this kind of DRFM jamming.

Due to the sensitivity to the initial condition, controllability, aperiodicity, noise-like character, outstanding autocorrelation performance, and thumbtack-shaped ambiguity function, chaotic signals draw much attention in the radar domain. In this paper, the appropriate original value for the chaotic system is selected to achieve excellent auto-correlation and cross-correlation performances by adopting the genetic algorithm.

Fig. 2 Processing results of frequency agility
(a) FFT, (b) ST-DFT

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The phased code signals of the $m$th pulse based on the chaotic signal can be represented as

$$s_m(t) = \sum_{n=0}^{N} C_m(k)p(t - kT_p)$$

$$= \sum_{n=0}^{N} p(t - kT_p)e^{j\phi_m,k}$$

$$m = 0, 1, \ldots, M$$

(9)

where $C_m(k)$ is the chaotic sequence, $C_m(k) = 1$ or $-1$, $\phi_m,k = 0$ or $\pi$, $p(t) = (1/T_p)$, $|t| \leq (T_p/2)$, and $T_p = T/N$, $N$ is the length of the phased code.

3 Simulation results

In this section, the effectiveness of jamming cognition, coherent for frequency agility, and waveform diversity will be demonstrated by three simulation experiments. Firstly, the performance of jamming cognition based on FrFT is analysed. Secondly, the coherent performance in the frequency agility scenario is discussed. Finally, the interference suppression performance of waveform diversity is discussed.

3.1 Results of precise jamming cognition

The results of precise interference cognition for the LFM radar signal and SMSP DRFM jamming are shown in Fig. 4; the original frequency and chirp rate can be estimated with (4) and (5) for frequency agility based on FrFT.

![Diagrammatic sketch of radar signal and jamming signal](image)

**Fig. 3** Diagrammatic sketch of radar signal and jamming signal

**Fig. 4** Results of precise interference cognition of radar signal and jamming

(a) Time domain, (b) FrFT result of the LFM radar signal, (c) FrFT result of jamming
3.2 Performance of the coherent method for knowledge-aided frequency agility

Since frequency agility results in the Doppler frequency, the coherence cannot be realised by traditional FFT processing, as shown in Fig. 2a. The ST-DFT algorithm is adopted to solve the problem, based on the range information of the target; the Doppler resulting from frequency agility could be repaired, and the energy of the target is accumulated, which is shown in Fig. 2b.

3.3 Anti-jamming performances of waveform diversity

The designed waveforms enable the radar to separate the signals being reflected off the true targets and the false reflectors being emulated by a jammer, which is manifested in Fig. 5b.

4 Conclusion

In this paper, we have addressed the intelligent ECCM technology, and developed a framework for the modern airborne radar, which includes the cognitive jamming detection and suppression, adaptive frequency agility, and waveform diversity. It can adjust the working parameters and ECCM steps in real time and optimise the radar performance in many different jamming scenarios. The ECCM performances are evaluated by numerical simulations. The results show that it enables the airborne radar to get the active position in EW.

5 References

[1] Haykin, S.: ‘Cognitive radar: a way of the future’, IEEE Signal Process. Mag., 2006, 23, (1), pp. 30–40
[2] Fan, Z., Zhu, G., Hu, Y.: ‘An overview of cognitive electronic warfare’, Electron. Inform. Warfare Technol., 2015, 30, (1), pp. 33–38
[3] Wang, F., Lei, Z., Huang, G., et al.: ‘Intelligent anti-jamming technique in radar’, Mod. Rad., 2014, 36, (1), pp. 80–82
[4] Zhang, M., Wang, L.: ‘A study on the technology of cognitive anti-jamming for fire control radar’, Mod. Rad., 2016, 38, (12), pp. 91–94
[5] Zhu, H., Sun, J., Yang, Y., et al.: ‘Interference suppression in cognitive radar based on environment perception’, J. China Academy of Electron. Inform. Technol., 2016, 11, (6), pp. 577–581
[6] Greco, M., Gini, F., Farina, A.: ‘Radar detection and classification of jamming signals belongs to a cone class’, IEEE Trans. Signal Process., 2008, 56, (5), pp. 1984–1993
[7] Li, Q., Li, J., Qin, J., et al.: ‘Method against radar's transmitting deceptive jamming in distance based on neural network’, Syst. Eng. and Electron., 2005, 27, (2), pp. 240–243
[8] Sparrow, M., Cakilo, J.: ‘ECM techniques to counter pulse compression radar’. United States Patent 7081846, 2006
[9] Utkarsh, S., Shyam, N.: ‘Application of fractional Fourier transform for classification of power quality disturbances’, IET Sci., Measurement and Technol. Res. Article, 2017, 11, (1), pp. 67–76.