Research on Anti-point Source Jamming Method of Airborne Radar Based on Artificial Intelligence

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Abstract. Due to the coexistence of multiple electromagnetic interference, the operational performance of radar equipment will be seriously affected. Therefore, it is necessary to study the anti-jamming problem of airborne radar. In view of the problem that airborne radar is easily affected by point source signal interference under the traditional method, an airborne radar anti-jamming method based on artificial intelligence is proposed. The anti-jamming method is designed. Firstly, the airborne radar is detected by frequency shift, and the detected information is analyzed to judge the jamming environment and identify the point source target intelligently. Then the suppression jamming filter is generated based on the analysis of the point source jamming information, and then the suppression jamming signal is output. Finally, the anti-jamming method of airborne radar is obtained. The performance results of the airborne radar anti-point source jamming method are analyzed by simulation experiments. Compared with traditional method, the proposed anti-jamming method can effectively suppress the point source jamming information, the radar signal is clearer and the anti-jamming effect is better. The results verify the effectiveness of the proposed method.

Keywords: Artificial intelligence · Airborne radar · Anti-point source interference · Anti-jamming method

1 Introduction

Airborne radar is the general name of all kinds of radar mounted on aircraft. It is mainly used to control and guide weapons, implement air alert and reconnaissance, and ensure accurate navigation and flight safety. The basic principle and composition of airborne radar are the same as those of other military radars [1]. Its characteristics are as follows: generally, there are antenna platform stabilization system or data stabilization device; generally, the band less than 3 cm is used; it is small in size and light in weight; and it has good seismic performance [2, 3]. This radar device provides target data interception radar for air-to-air missiles, rockets and aerial guns, bombing radar for aiming at bombing

S. Liu and L. Xia (Eds.): ADHIP 2020, LNICST 348, pp. 154–164, 2021.
https://doi.org/10.1007/978-3-030-67874-6_15

surface targets, guiding air-to-surface missiles and providing target information for pilots, air reconnaissance and terrain mapping radar for providing position and topographic data of surface targets, and observation of meteorological conditions, air targets and ground targets. The shape and features ensure accuracy and safety [4]. With the development of electronic technology and information technology, electronic information equipment has played a more and more important role in modern warfare. The mode of modern warfare has changed from simple fire countermeasure to complex electromagnetic countermeasure. Many kinds of electromagnetic interference coexist in the battlefield, which seriously affects the operational performance of radar equipment [5].

At present, many scholars have done a lot of research on anti-jamming of airborne radar. In reference [6], a performance evaluation method of PCL radar based on frequency modulation is proposed. This method studies a PCL radar system based on FM, and attempts to quantify its performance under different jamming waveforms, that is, wideband noise and single tone jamming on carrier. The results show that the effective jamming can be achieved under relatively low jamming power, but the suppression effect is not good in the face of point source interference information. Reference [7] based on the geometric model of synthetic aperture radar (SAR), a fast algorithm for deception jamming in large scenes for different SAR systems is proposed. Firstly, the template deception image is transformed into time domain signal by inverse imaging algorithm. Then the transformed signal is convoluted with the SAR signal received by the enemy to deal with the electronic countermeasure (ECCM) technology. Finally, the jamming signal is transmitted to the enemy's SAR system to achieve the purpose of deception. The experimental results show that the deceptive jammer has the ability to deceive SAR system, but the radar signal obtained is not clear enough.

In view of the above problems, in order to meet the needs of modern warfare and improve the operational performance of weapon system in complex electromagnetic environment, airborne radar adopts advanced active phased array system. With the help of some principles and performances of AI, AI produces an intelligent machine that can respond in a similar way to human intelligence. The research in this field includes robots, language recognition, image recognition, natural language processing and expert systems. Since the birth of artificial intelligence, theory and technology have become increasingly mature, and the field of application has been expanding. Airborne radar is often disturbed by point source signals when it works, which leads to erroneous judgment of radar system and affects decision-making. Therefore, applying the working principle and technical characteristics of AI system to airborne radar system can effectively counter various electromagnetic interference modes and complete detection and tracking of incoming targets in complex electromagnetic interference environment. The normal operation of fire control system can effectively improve the survivability of weapon equipment on the battlefield.

2 Design of Anti-point Source Jamming Method for Airborne Radar

It is an inevitable trend for radar to develop towards cognitive and intelligent. Airborne radar can be regarded as the rudiment of intelligent radar. This kind of radar can work at the weakest frequency of the enemy's jamming power, or force jammers to implement broadband jamming and reduce the jamming power density, so as to realize the function of anti-jamming. The intelligent anti-point source jamming method of airborne radar should have such a continuous cycle of recognition, determination, processing, re-recognition, re-determination and re-processing. This requires that radar should have several characteristics: Firstly, the comprehensive perception characteristics of jamming environment. Radar anti-jamming system can respond to the change of jamming environment in a specific way without external direct interference and guidance, and update the model base, characteristic parameter base and knowledge base of radar jamming continuously according to its internal state and perceived jamming environment information. Secondly, intelligent interference recognition and classification based on comprehensive features, with intelligent anti-jamming measures, intelligent anti-jamming will have more complex criteria and cognitive channels, can deal with more kinds of interference. Through strategy optimization deduction, anti-jamming strategies that can be applied to many complex scenarios are found, and various factors are parameterized. Computer quantitative analysis is used to solve complex coping strategies. By analyzing and extracting the jamming features in radar channel, the classification of jamming is completed, and corresponding jamming countermeasures are invoked for different types of jamming. The core of the Intelligent Airborne Radar anti-point source jamming method is to automatically identify the jamming type and take anti-jamming measures to complete the jamming countermeasure. Its main system structure is shown in Fig. 1.

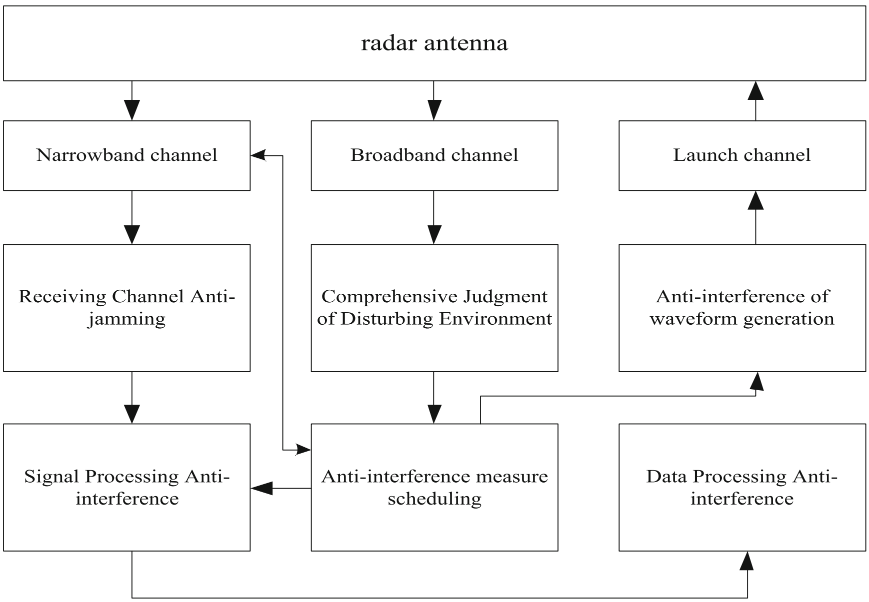

Fig. 1. Working principle of intelligent anti-jamming

From the working principle in the figure, it can be seen that the signals received by radar antennas between airborne radar systems are input into broadband channel and narrowband channel. After a series of analysis and processing of jamming environment, signal processing and anti-jamming measures scheduling, the anti-jamming waveform is finally generated, and returned to the airborne radar antenna through transmission channel, and finally the airborne radar antenna is realized. The ultimate purpose of radar system is to against the point source interference.

2.1 Frequency Shift Detection of Airborne Radar

Because the frequency modulation slope and pulse width of airborne radar transmitting signals at different periods are invariable, but the initial frequency is different, the position of target echo signal and jamming signal in frequency domain is different, and the frequency shift value is different, and the overlap in frequency domain is also different. According to the different overlap degree of target echo signal, jamming signal and matched filter reference function (impulse response function) in frequency domain, the purpose of jamming suppression can be achieved by distinguishing target echo signal, false target and deceptive jamming signal. The radar signal transmitted in the n pulse period of radar can be expressed as:

$$S_n(t) = rect(\frac{t}{T}) \exp\{j[2\pi f_0 t + 2\pi f_n t + \pi \mu t^2 + \varphi_0]\} \tag{1}$$

In the formula, μ is the signal frequency modulation slope, f_0 is the signal bandwidth, φ_0 is the signal carrier frequency, f_n is the initial phase, 6 is the frequency modulation starting frequency of the n pulse cycle signal. In different pulse periods, the initial frequency of FM signal is a set of random sequences known to radar. Since the radar first downconverts the received signal and then processes the signal, it can be assumed that $f_0 = 0$, $\varphi_0 = 0$. The pulse compression of pulse compression radar is generally large, so the spectrum function of the reference signal of matched filter can be approximately expressed as follows:

$$H(f) = \frac{1}{\sqrt{\mu}} rect\left(\frac{f - f_n}{B}\right) \bullet \exp\left[j\left(\frac{\pi(f - f_n)^2}{\mu} - \frac{\pi}{4}\right)\right] \tag{2}$$

In the n pulse period, the jamming equipment generates jamming signal by using the radar signal of the previous m pulse period, and the radar signal of the n pulse period enters the radar receiver at the same time. The received signal can be expressed as:

$$x_n(t) = s_n(t - \tau_n) + j_n(t - \tau_n) \tag{3}$$

After the radar signal is reflected by the target, the spectrum of the target echo signal received by the receiver is $S_n(f)$, and the spectrum of the jamming signal component is derived from the spectrum $J_n(f)$. Considering $f_m < f_n$, the spectrum function of the output pulse pressure signal of the echo signal is the product of the spectrum of the echo signal and the spectrum of the reference function of the matched filter. The interference signal enters the spectrum function of the output signal of the matched filter, and carries on the inverse Fourier transform to obtain the output pulse pressure signal of the interference signal as follows:

$$\begin{aligned} j_0(t) &= \int_{-\infty}^{+\infty} J_0(f)\exp(j2\pi ft)df \\ &= \frac{B+f_m-f_n}{\mu}\sin c\left[(t-\tau_{jn}-\frac{f_m-f_n}{\mu})(B+f_m-f)\right] \\ &\cdot \exp\left[j\pi(t-\tau_{jn})(f_m+f\right] \end{aligned} \tag{4}$$

Because the target echo signal coincides with the reference function in frequency domain, the output signal bandwidth is B. Because the interference signal only coincides with the reference function in frequency domain, the output signal bandwidth is only $B+f_m-f_n$. When $f_n-f_m<B$, the output value of the interference signal can be obtained by pulse compression. When the radar received signal is processed by frequency forward shift, the coincidence of target echo signal and reference function in frequency domain will be reduced, while the coincidence of interference signal and reference function in frequency domain will be increased first and then decreased.

2.2 Intelligent Point Source Target Recognition

After the airborne radar frequency shift detection and pulse doppler processing, the target detection is carried out, and the range doppler information of the target is depicted on the doppler plane. For example, there are three point sources jamming in distributed networked airborne radar. Because the doppler of false target is modulated by jammer, the doppler offset received by radar at each station should be equal. In the first step of the algorithm, the doppler information of the target is compared. In order to avoid the tedious steps caused by the combination, only the doppler information is used to sort the target. The doppler information of the false target will be relatively concentrated in a small window and far away from the doppler information of the real target. The second step is to further recognize the jamming by using the distance dimension characteristics of the jamming, and finally determine the jamming target, and then suppress it. It should be pointed out that in the process of these two steps, the target distance and doppler information still need to be retained in the data. In order to facilitate the analysis without losing generality, considering that there is only one real target, and the jammer modulation produces a false target. The target detection algorithm is used to process each radar pulse and doppler. After detection, the doppler and range information of the target can be obtained. Because of the existence of jamming signals, radar can not distinguish between true and false targets before jamming detection, so the radar detects two targets at this time. Then all the doppler information is sorted. Because the doppler shift of the false targets is equal, and affected by noise and doppler resolution, the doppler shift of the processed false targets is approximately equal, then they will be clustered together and have a small interval between each other after sorting [8, 9].

The sorted data is processed by sliding window. The window length is ε and a threshold value is preset. It is related to doppler resolution. The sketch shows that when and only when the initial position of the window is located in the first false target doppler, the number of targets in the window will be N, and in other cases the number of targets in the window is less than N. When the number of targets in the window is N, consider these targets as false targets, and then find out the range doppler coordinates corresponding to this point, and mark them as interference. Due to the existence of multiple radars in distributed radars, with the decrease of signal-to-noise ratio, the doppler information may be deviate from the real value, which may lead to the absence of the number of targets in the window [10–12]. In order to be more consistent with the actual situation, broaden the number of false targets in the window to $n(n < N)$, then n targets falling in the window will be identified as false targets.

After the preliminary judgment of the jamming, in order to increase the accurate distance and speed deception jamming information, the judgment of the distance dimension feature is introduced to judge whether the real target delay is approximately equal, if equal, using the results of the first step, the final judgment is false target. Based on the range-velocity joint deception point source interference suppression method of airborne arrival, target detection and interference suppression are combined. Because of the characteristics of deception jamming, the jamming signal can also obtain processing gain at the receiving end, so that the energy can be accumulated. In the first step, do not distinguish the jamming target, but process the echo signal in two-dimensional range and velocity. After obtaining the range doppler information of the target and the jamming, the jamming is identified preliminarily by using the characteristics of the jamming in doppler, and the number of targets in the discriminant window is adjusted according to the possible errors. The second step, combined with the characteristics of the interference in the distance dimension, further identifies the interference [13–15]. Finally, the target is judged by combining the results of two steps. Using the result of judgment, the radar information of the sub-node which is identified accurately is utilized, the interference is eliminated, the target is retained, and the correct detection of the target is realized.

2.3 Generating Suppression Interference Filtering

The adaptive suppressed jamming beamforming based on the linear constrained minimum variance criterion is to sum the received signals of each airborne radar element by weighting, and minimize the output power of the array under the constrained condition that the signal gain in one direction is constant. The detailed steps of the adaptive suppression jamming beamforming method based on linear constrained minimum variance criterion are as follows: Knowing that the received carrier radar signal sequence $X(t) = \{x_1(t), x_2(t), \ldots x_k(t)\}$ is a N × M dimension matrix (where N is the number of antenna arrays and M is the number of snapshots), the search space of OTH radar is divided into P azimuths. The constraints are set and the covariance matrix of the array is obtained as follows:

$$R = E\{X(t)X^H(t)\} \tag{5}$$

In the formula, E is the unit matrix, and H represents the matrix constraints of airborne radar. In practical calculation, the covariance matrix of the array is estimated to be R by the finite number of snapshots $X(t)$, and then the adaptive weight vector for suppressing interference is W. SVD decomposition of R is carried out. The first P-1 eigenvalue $\lambda_1, \lambda_2, \ldots \lambda_{P-1}$ and the eigenvector corresponding to the eigenvalue $v_1, v_2, \ldots v_{P-1}$ are obtained. The weight vector W is projected into the interference subspace of $v_1, v_2, \ldots v_{P-1}$ signals, and the weight coefficient W_e is obtained. Thus, when the number of interference sources and sources is known, the output value of beamforming can be obtained by formula 6 without knowing the direction of interference and sources.

$$Y(t) = W_e^H x(t) \tag{6}$$

2.4 Output Suppression of Interference Signal to Realize Anti-jamming Method

The received signal of airborne radar enters the matched filter. Its essence is to receive the signal and convolute it with the reference function of the filter. The conversion to the frequency domain is the multiplication of two frequency functions. Figure 2 is a frequency domain schematic diagram of matched filter reference signal, target echo signal and deception jamming signal.

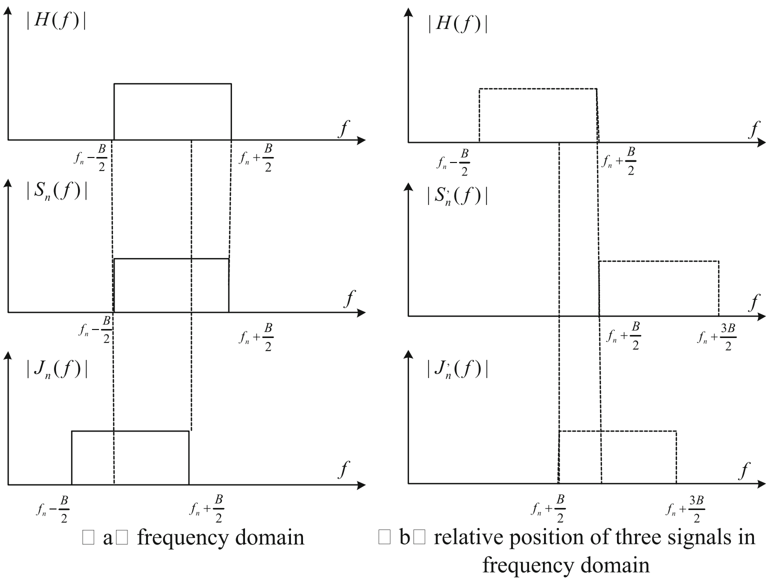

Fig. 2. Signal frequency domain diagram

Because the interference signal has the same bandwidth as the reference function, but the starting frequency is different, the overlap part decreases when the two signals multiply in the frequency domain, which makes the amplitude of the output signal of the interference signal decrease, while the target echo signal coincides with the reference function in the frequency domain completely, so it has a good energy aggregation characteristic. If the radar received signal is frequency shifted, the frequency of the target echo signal will not coincide with the frequency domain of the reference signal. With the increase of frequency shift, the frequency domain of the two signals will not coincide at all. When the frequency shift is signal bandwidth B, the relative position of the signal in frequency domain is shown in Fig. 2 (b). At this time, the target echo signal and the reference function will not overlap in frequency domain, and the output signal will be very small, while the interference signal is different from the target signal's starting frequency. When the frequency shift is made, it will still overlap with the reference signal in frequency domain. Therefore, the radar received signal can be frequency shifted and the frequency shift value can be obtained $\Delta f = B$. According to the peak position t_j° of the output signal, the peak position $t_j = t_j^\circ - \Delta t$ of the output interference signal of pulse pressure before frequency shift is determined, so that the interference can be suppressed by setting a certain width of time domain. The interference suppression methods are summarized as follows:

Step 1: The radar received signal $x(t)$ is frequency shifted, the frequency shift value is $f_M = B$, and the frequency shift signal $x^\circ(t)$ is obtained.

Step 2: Identifies the interference environment by passing the frequency-shifted signal through a matched filter, determines the point source information to obtain the pulse compression output signal, and determines the time delay t_j° corresponding to the peak value.

Step 3: Pulse compression is applied to the received signal. When the time delay of the output signal is $t_j = t_j^\circ - \Delta t$, the initial frequency of the time domain will be greater than the initial frequency of the target echo signal.

Step 4: Frequency shift of the received signal $x(t)$ of airborne radar is carried out. The value of frequency shift is used to get the signal after frequency shift. Step 2 and Step 3 are repeated to realize the whole airborne radar anti-point source jamming method.

3 Experimental Analysis

The performance of airborne radar anti-point source jamming method is tested and analyzed. Firstly, the simulated complex jamming experimental environment is constructed, which consists of shielding darkroom, turntable, radiation array, complex electromagnetic environment signal simulation system, radio frequency simulation laboratory control system, data recorder, demonstration and verification computer evaluation system, radar display control system and physical radar.

Target simulation and clutter simulation equipment in complex electromagnetic environment signal simulation system receives radar synchronization signal, and simulates target signal and clutter signal interfering with radar point source; electronic support equipment in complex electromagnetic environment signal simulation system detects radar signal by arrays of horns, and transmits it to jamming simulation equipment as samples to simulate various deceptive jamming required. With suppressing interference; In the complex electromagnetic environment signal simulation system, the radar emitter simulator can simulate various radar signals independently to help simulate the realistic electromagnetic environment. At the same time, it can also evaluate the performance of the radar against the co-frequency asynchronous jamming and the performance of the reconnaissance signal when the airborne point source phased array radar starts the EsM function. The three-axis turntable is used to simulate the three-axis motion of the airplane. The received signal passes through the radar receiving channel and enters the radar processor for signal processing. The information of radar searching and tracking target is displayed on the avionics screen. At the same time, the digital data received by the radar is recorded by the recorder for post-analysis and evaluation. The traditional anti-jamming method is used as the experimental contrast group. The experimental environment of the experimental group and the control group is point source jamming environment, and the airborne radar equipment used is the same. The purpose is to ensure the uniqueness of the experimental variables, so that the experimental data obtained is more accurate, and the final experimental analysis conclusion is more valuable. Start up the complex point source jamming environment, using different anti-jamming methods, the radar signal results are shown in Fig. 3.

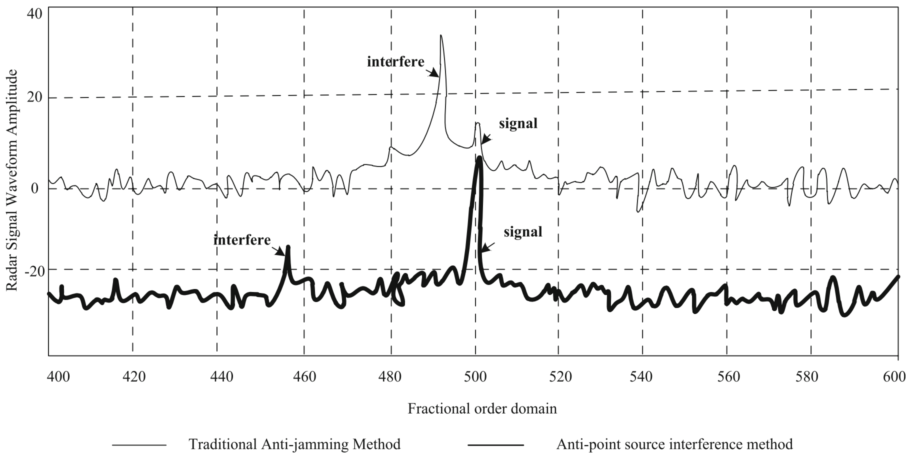

Fig. 3. Experimental results

From the radar waveform of the experimental results, it can be concluded that the waveform of interference points in traditional anti-jamming methods is more obvious than that of radar signals, and the distance between the two waveforms is relatively close. It is easy to mistake the jamming signals as radar signals for recording, resulting in errors in the information obtained. The designed anti-point source jamming method, from the experimental results, effectively suppresses the intensity of the jamming signal, makes the performance of the radar signal clearer, and pulls the jamming information and radar information apart for a certain distance, thus realizing the anti-jamming function more efficiently. This is because in the process of airborne radar anti-jamming design, firstly, the airborne radar is detected by frequency shift, and then the jamming environment is judged and the point source target is identified intelligently. According to the analysis of the point source interference information, the suppression jamming filter is generated, and then the suppression jamming signal is output, so as to effectively suppress the interference information.

4 Conclusion

Faced with the increasingly complex electromagnetic environment and interference, radar anti-jamming technology needs to be developed continuously. Although the radar intelligent anti-jamming technology is still in its infancy, the urgency of the radar anti-jamming situation objectively requires the radar to develop in the direction of intelligence. Radar intelligent anti-jamming technology, as the concrete technology realization of intelligent radar and cognitive radar, will surely get considerable development. In order to overcome the shortcomings of traditional methods, an artificial intelligence-based airborne radar anti-point source jamming method is proposed. The experimental results show that the proposed method has better anti-jamming performance and can effectively solve practical problems.

References

1. Shi, C., Wang, F., Sellathurai, M., et al.: Low probability of intercept-based distributed MIMO radar waveform design against barrage jamming in signal-dependent clutter and colored noise. IET Signal Process. **13**(4), 415–423 (2019)
2. Shen, W., Xu, F., Wu, G.X., et al.: A multi-station angle fusion anti-jamming method. Modern Radar, **22**(1), 47–50 (2018)
3. Tao, Z., Shaoqiang, C., Huayu, F., et al.: Design and processing of a novel chaos-based stepped frequency synthesized wideband radar signal. Sensors **18**(4), 985 (2018)
4. Lee, G.H., Jo, J., Park, C.H.: Jamming prediction for radar signals using machine learning methods. Secur. Commun. Netwk. **2020**(3), 1–9 (2020)
5. Wen, C., Peng, J., Zhou, Y., et al.: Enhanced three-dimensional joint domain localized stap for airborne fda-mimo radar under dense false-target jamming scenario. IEEE Sensors J. **18**(10), 4154–4166 (2018)
6. Paine, S., O'Hagan, D.W., Inggs, M., et al.: Evaluating the performance of fm-based pcl radar in the presence of jamming. IEEE Trans. Aerospace Electronic Syst. **55**(2), 631–643 (2019)
7. Saeedi, J.: A new hybrid method for synthetic aperture radar deceptive jamming. Int. J. Microwave Wireless Technol. **4**(1), 1–14 (2019)
8. Hanbali, S.B.S.: A review of radar signals in terms of Doppler tolerance, time-sidelobe level, and immunity against jamming. Int. J. Microwave Wireless Technol. **10**(10), 1–9 (2018)
9. Liu, S., Li, Z., Zhang, Y., et al.: Introduction of key problems in long-distance learning and training. Mobile Netwk. Appl. **24**(1), 1–4 (2019)
10. Liu, S., Glowatz, M., Zappatore, M., et al.: e-Learning, e-Education, and Online Training. Springer International Publishing, Berlin (2018)
11. Fu, W., Liu, S., Srivastava, G.: Optimization of big data scheduling in social networks. Entropy **21**(9), 902 (2019)

12. Shi, C.G., Wang, F., Salous, S. et al.: Adaptive jamming waveform design for distributed multiple-radar architectures based on low probability of intercept. Radio Sci. **54**(1–2), 72–90 (2019)
13. Enzheng, Z., Benyong, C., Hao, Z., et al.: Laser heterodyne interference signal processing method based on phase shift of reference signal. Opt. Express **26**(7), 8656 (2018)
14. Lu, M., Liu, S.: Nucleosome positioning based on generalized relative entropy. Soft. Comput. **23**(19), 9175–9188 (2018). https://doi.org/10.1007/s00500-018-3602-2
15. Joshi, H.D., Kaur, R., Singh, A.K., et al.: An improved method for deceptive jamming against synthetic aperture radar. Int. J. Microwave Wireless Technol. **10**(1), 115–121 (2018)