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Na Zhang (✉ zhangn8202@163.com)

Naval Aviation University Qingdao Campus

Xiaomei Zhang

Naval Aviation University Qingdao Campus

Dongxiang Tao

Naval Aviation University Qingdao Campus

Xiaojia Ji

Naval Aviation University Qingdao Campus

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Signal Processing and Recognition Technology and Simulation of Radar Communication Integrated System

Na Zhang^{1,a*}, Xiaomei Zhang^{1,b}, Dongxiang Tao^{1,c} and Xiaojia Ji^{1,d}

¹Naval Aviation University Qingdao Campus, Qingdao 266100, Shandong, China

^azhangn8202@163.com

^bdhzmqd@163.com

^ctdx72@163.com

^djixiaojia2002@163.com

*Corresponding Author

Abstract: The integrated radar communication system combines the functions of radar and communication systems. It has attracted wide attention because of its advantages in effectively reducing electromagnetic interference between equipment and reducing equipment volume. However, there is no complete radar communication integrated signal design scheme so that the radar and communication system can operate well at the same time to achieve better detection and communication performance. In order to achieve better results for the integration of radar communication, this article summarizes and analyzes the existing research on integration of radar communication, and summarizes the realization of two design ideas of superimposed signal and single signal. The basic system composition of pulse radar and continuous wave radar, the working mechanism of radar speed and distance measurement and the basic composition of communication system are described. Research has proved that through the integration of radar communication, signal processing and identification are greatly improved, the signal transmission strength is more than 30% stronger than that without integration, and the transmission distance is 20% higher. Moreover, there are also great differences between the different integration methods. The fuzzy function used in this article is better than other experimental methods. This shows that the integrated radar communication system is the trend of future research on signal processing and recognition.

Keywords: Radar Communication Integration, Signal Processing, Signal Recognition, Ambiguity Function

1 Introduction

With the increasing performance of radar systems and communication systems, the application range of the two continues to widen, and the gap between radar and communication systems has begun to gradually merge [1]. The working frequency band of radar has covered the range from HF band to EHF band. The working frequency of ground-wave over-the-horizon radar is as low as 2MHz, while the working frequency of lidar is even higher than 240GHz. And the working frequency band of the communication system is no longer limited to the high-frequency to UHF band, and the working frequency ranges of the two are beginning to overlap gradually. In view of this, it is undoubtedly feasible to integrate the radar system and the communication system, transmit communication information through the radar equipment, and realize the integration of radar communication. And due to the similarity of the hardware and structure of the two systems, the integrated design can make the existing Radar and communication systems make fewer modifications [2].

Radar equipment is used to obtain target characteristic parameters. As the complexity of warfare increases, radar needs to achieve high accuracy, long range, high resolution and multi-target

measurement as much as possible. Communication equipment is used for the exchange of battlefield information under the premise of low probability of interception. Since World War II, the improvement of communication equipment is more reflected in the convenience and the improvement of battery life [3]. By realizing the integration of the radar communication system, the communication system can use the high transmission power of the radar system to carry more energy and transmit a longer distance; the narrow beam directional antenna of the radar can provide good concealment for the communication signal, only Information can only be received within the radar antenna beam range, thereby reducing the possibility of being detected by the enemy; and the integration of the two reduces the size of the equipment, and reduces the load and cost of equipment that require high mobility such as aircraft and ships. , It is of great help to improve the overall combat performance. In view of this, the research on the integration of radar communication is very necessary [4].

RALPHH.CAGER and others designed a Ku-band radar communication fusion system for NASA's orbiter. This system can work as a radar system when converging with other orbiters, and it can also work through the orbit and data relay satellite system. The two-way communication between the track and the ground realizes the purpose of radar and communication [5]; scholars such as Shrawan C. Surender use ad-hoc networks, wireless communication and random waveforms in radar sensors to meet the demand for covert situational awareness, using ultra-wideband Random noise radar has the characteristics of low interception probability and low detection probability. A notch filter is used to cut part of the radar signal spectrum, and the communication data is cleverly embedded in it for transmission [6]. Xu.S.J proposed a radar communication fusion system based on direct sequence spread spectrum ultra-wideband radar (DS-UWB). The system adopts the idea of CDMA, using two orthogonal pseudo-random (PN) codes to spread the radar signal and the communication signal separately to avoid mutual interference [7]. Scholars such as AboulnarHassanien proposed a "dual-function radar communication system" based on the idea of space division multiplexing. The system uses beamforming technology to make the main lobe of the antenna radiation signal used for the radar, and the communication information is located in the side lobe. When there is a multi-user situation Multiple side lobes can be used for communication [8].

In view of the more or less limitations and deficiencies in the current implementation of radar communication integration, this paper proposes a conversion method to derive the ambiguity function of the proposed radar communication integration waveform. The ambiguity function is similar to the traditional The ambiguity function of FM continuous wave radar has similar forms and properties. The design plan of radar communication integration is reviewed. The analysis concludes that the integration is mainly divided into two ways: superimposed waveform and integrated waveform, and pointed out the advantages and disadvantages of the respective solutions. Using their properties, the sine waveform in communication can be used For radar speed and range measurement, communication and radar functions will be basically unaffected. The implementation process is explained in detail through necessary simulation analysis, and the correctness of the theoretical derivation is verified.

2 Radar communication integration method

2.1 Radar

The working principle of radar is very similar to the principle of acoustic reflection. If you send a sound to an object that reflects the sound, you will get an echo. When the speed of sound is known, the time required for the echo to return can be converted into the distance and approximate direction of the object [9-10]. Radar emits electromagnetic waves in a very similar way. The signal emitted by the radio frequency front end of the radar transmitter is transmitted to the reflecting object and reflected from the

transmitting object back to the radar receiver. The radar uses a small part of the energy of the reflected echo to determine the direction and distance of the reflecting object.

According to the type of waveform emitted by the radar, the radar can be divided into pulse radar and continuous wave radar system. The pulse radar transmitter and receiver share the antenna, the radar transmits a high-power pulse signal in a short time, and the rest of the time waits to receive the reflected echo [11]; while the continuous wave radar uses a separate transmitter and receiver, Thus, the reflected echo from the target can be received while continuously transmitting a continuous radar waveform.

Pulse radar is a radar device that transmits short and high-power pulses. It receives echo signals during the silent period (that is, when the pulse is not transmitted). Before the measurement is completed, the radar transmitter is turned off [12]. The characteristic of this method is that the radar pulse modulation has a very short transmitting pulse. The duration of the transmitting pulse is recorded as μ , and there are very large pulses between the transmitting pulses $T \geq \mu$, which is called the receiving time. When the radar is fixed somewhere or stationary, the distance of the reflecting target is determined by the measured round-trip time between the received echo and the transmitted echo. The transmitted signal of pulse radar can be simply expressed as:

$$s(t) = A t * \sin[2\pi f(t) * t + \gamma(t)] \quad (1)$$

The function $A(t)$ is the amplitude change with respect to time, that is, amplitude modulation. In the simplest case, the transmitter is turned on for a short period of time (time μ), and remains off (time $T - \mu$) for the rest of the pulse repetition interval. Since the radar only emits energy within a pulse period, and waits for the echo to be received in the silent state during the remaining time, the duty factor can be defined $d_t = \mu / T$. The average transmit power of the radar can be expressed as:

$$P_a = P_t * d_t = \frac{P_t * \mu}{T} \quad (2)$$

Among them P_t is the peak transmit power of the radar. Single pulse energy:

$$E_p = P_t \mu = P_a T = P_a / f_{PRF} \quad (3)$$

After the radar transmits a pulse, there needs to be enough waiting time to receive the target echo before the next pulse is transmitted. The maximum round-trip delay that will not cause distance ambiguity is T , and the corresponding maximum non-ambiguity distance is defined as R_u , which can be expressed as:

$$R_u = \frac{cT}{2} = \frac{c}{2f_{PRF}} \quad (4)$$

We define P_u as the power reflected from the target to the radar. The total power transmitted to the radar receiver can be expressed as:

$$P_{Du} = \frac{P_u}{4\pi R^2} A_e = \frac{P_D \sigma}{4\pi R^2} A_e = \frac{P_t G \sigma}{(4\pi R^2)^2} A_e \quad (5)$$

In actual operation, the echo signal received by the radar receiver is not only the reflected echo of the target, but also random noise. Then the radar equation can be expressed as:

$$(SNR) = \frac{p_t G^2 \lambda^2 \sigma}{(4\pi)^3 k T_0 B L R^4} \quad (6)$$

The pulse radar antenna concentrates electromagnetic energy in a narrow beam. When the center of the antenna beam is exactly at the target, the target reflects the most energy and the radar receives the strongest echo signal; when the antenna beam deviates from the target, the target reflects The energy is reduced, and the intensity of the echo signal is weakened [13-14]. Therefore, when the received echo signal has the strongest energy, the direction of the antenna beam is the direction of the target relative to the radar. If you need to improve the accuracy of radar angle measurement, you can choose a larger antenna to emit a narrower beam. The radar operation framework is shown in Figure 1:

Figure 1. Radar operation framework

2.2 Communication Principle

The radar system uses the emitted electromagnetic waves to propagate in free space, and the received echo is obtained after being reflected by the target to extract state information such as the range and speed of the target [15]. The wireless communication system uses electromagnetic radiation energy to transmit information from the transmitter to the receiver. The information to be transmitted is processed by the communication transmitter and converted into a waveform suitable for transmission in free space. The radiated electromagnetic energy is transmitted to the receiver after the influence of the channel, and the receiver performs a series of processing on the received signal to restore the transmitted data.

The baseband transmission signal of the communication system can be simply expressed as:

$$s(t) = A(t) \cos[2\pi f(t)t + \gamma(t)] \quad (7)$$

This is completely consistent with the form of the radar signal. The difference is that the and of the communication system $A(t)$, $f(t)$ and $\gamma(t)$ respectively represent the amplitude, frequency and phase of the signal, which contains the communication information to be transmitted. The way of embedding communication data corresponds to amplitude modulation, frequency modulation and phase modulation respectively. In the transmission process, a suitable modulation method can be selected according to the performance index requirements of the system [16]. For the digital bandpass transmission system, using

the discrete value characteristics of the digital signal, the modulation mode corresponds to the discrete form, expressed as amplitude keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK). In the case of binary, information is characterized by "0" and "1", which can be mapped into binary amplitude, frequency or phase states during modulation [17-18].

Since the modulation and demodulation of the chirp signal is difficult to implement in hardware in actual operation, it is difficult to directly apply the chirp signal to the communication system. An interesting fact is that the fractional Fourier transform of a sinusoidal signal is a chirp signal, so it is possible to consider using the sinusoidal signal in communication as the integrated waveform of radar communication.

The signal generated by the transmitter can not only realize the radar function but also communicate, and completely integrate the radar and the communication, and no longer need two sets of signal generation equipment and superimpose [19]. The receiving end uses a power divider to divide the received signal into radar and communication channels, and perform signal processing respectively to extract relevant information. Obviously, the idea of "combining two into one" is more in line with the needs of radar communication integration, and future research directions will also work towards it.

2.3 Integrated System

One of the problems in realizing the integration of radar communication is how to introduce integrated signals on the basis of existing systems and equipment, and gradually update and upgrade the system, so as to achieve that the current equipment can be put into use with a small amount of modification and reduce To achieve the purpose of cost. One of the solutions is to select the traditional radar waveform or communication waveform for the integrated waveform design of radar communication, that is, modulate the communication data based on the radar waveform or realize the function of the radar based on the communication waveform [20-21].

In terms of system structure, the radar transmitter performs power amplifier and other equipment on the generated waveform and then transmits it through the antenna, and the receiver performs matched filtering processing on the received signal to obtain target information. The distortion of the signal waveform does not affect the radar detection; the communication system is due to The waveform contains information, which requires operations such as encoding, modulation, decoding, and demodulation of the signal. Waveform distortion will undoubtedly lead to information errors and affect communication performance. When the integration of radar communication is realized based on radar waveforms, a series of communication modules for improving the effectiveness and reliability of the system need to be added to the radar equipment, and the system has a high degree of complexity [22]. When the integration of radar communication is realized based on the communication waveform, the focus is on how to make the communication waveform have the function of radar. If this function can be achieved, the integrated system does not need to add additional radar modules, and the implementation complexity is relatively low [23].

Since the transmission waveform of the integrated radar communication system is in the form of a communication waveform, the transmitted waveform does not contain radar information, so the communication receiver can complete normal communication reception without modification. The realization of the radar function is based on the communication signal. After performing the fractional Fourier transform on the above, the principle of linear frequency modulation is used to obtain the target range speed information [24-25]; the communication receiver and the radar receiver perform different signal processing on the received signal to extract the signal contained The two receiving systems do not interfere with each other, and the radar and communication share the power and other resources of the

entire transmitter, so the radar system will not interfere with the communication system. However, since the realization of the fractional domain chirp continuous wave radar requires continuous phase of the transmitted waveform, it is necessary to select a suitable modulation method to meet the requirements when modulating communication data.

In the choice of the transmitted signal waveform, pulse radar usually modulates $A(t)$ and $f(t)$ in the formula. $A(t)$ is a rectangular wave with a narrow time width, and $f(t)$ is used to transmit a narrow pulse signal, which corresponds to a large bandwidth in the frequency domain, thereby achieving high range resolution. $f(t)$ usually uses linear frequency modulation, namely:

$$f(t) = f_o + \mu t \quad (8)$$

f_o is initial frequency, μ is the tuning frequency. In this case, the frequency of the signal increases with time. The chirp method solves the contradiction between the time width and bandwidth of the pulse signal: under the traditional modulation method with constant frequency, the time width-bandwidth product of the signal is constant, which means that the time width and bandwidth cannot be increased at the same time, which corresponds to radar detection. It is the contradiction between the detection range of the radar and the range resolution.

The continuous communication waveform is also not suitable for the detection system of pulse radar. On the other hand, continuous wave radar emits a continuous waveform, and its frequency is in the form of linear frequency modulation, which is not conducive to the modulation and demodulation of communication information. The frequency in communication is usually constant, and theoretically it is not suitable for continuous wave radar transmission. The problem of signal incompatibility restricts the space for integrated signal design. But in the perspective of the transform domain, this is not always the case.

The use of one waveform to achieve the integration of radar communication eliminates the mutual interference between the two signals. The combined signal saves resources in the time domain, frequency domain, code domain or space domain. As a highly integrated waveform, it is the integration of radar communication. The ideal waveform. However, in the current system design, OFDM waveform is usually used as the integrated radar communication signal. Although it is easy to implement, due to the peak-to-average ratio and sensitivity to Doppler shift of OFDM, its radar function can only be applied to short-range, low-speed. The scope of application is not wide. This single waveform contains communication data. After the simple processing of the fractional Fourier transform, the target information of the radar can be obtained. This allows the radar and communication to share all resources in the time-frequency code space, and for radar or communication systems. It is easy to implement.

A simple and easy integrated radar communication system can choose continuous wave radar as the system's transmitting and radar receiving equipment, and the transmission waveform selects the single-frequency signal in the communication. In the realization of communication, it uses a radar transmitter to transmit a higher-power communication signal, which is actually no different from a traditional communication system, except for the difference in power, so that the communication receiver can perform signal decoding according to the traditional communication signal. Tune. In the realization of radar, although the transmitted signal form is not a chirp signal, the angle in the fractional transform domain is consistent with the traditional chirp continuous wave radar. In the frequency domain or the fractional transform domain, its essence is a modulation frequency (Or fractional domain frequency) for signals that increase linearly with time, there is actually no essential difference in the detection

mechanism of radar.

2.4 Signal Processing Recognition Model

Chirp signals are widely used by radar designers to improve the relationship between the resolution and range of radar systems. When applied to communication systems, they can have anti-interference and anti-multipath fading characteristics. The frequency of the chirp signal changes linearly with time, but in actual operation, it is difficult to implement the modulation and demodulation of the chirp signal in hardware, so it is difficult to directly apply the chirp signal to the communication system [26].

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The $f(t)$ fractional frequency of the signal is denoted as u , and the center of the fractional domain spectrum can be obtained by calculating the average value of the fractional frequency. According to the definition of the Hermite operator in signal analysis, the average value of the fractional frequency $\langle u \rangle$ can be passed through the signal $f(t)$ is calculated, and the score of $f(t)$ is transformed into $F(t)$, then the mean value can be obtained:

$$\langle u \rangle = \int_{-\infty}^{\infty} u |F\alpha(u)|^2 du = \int_{-\infty}^{\infty} f^*(t) \mathcal{E}^a f(t) dt \quad (9)$$

Which $\mathcal{E}^a$ represents the fractional frequency operator, and its time domain expression is:

$$\mathcal{E}^a = \cos \alpha * \delta + \sin \alpha * \lambda \quad (10)$$

In the formula, δ is a time operator and λ is frequency operator. Using the relationship between the Hermite operator and the instantaneous variable, the instantaneous fractional frequency u of the signal $s(t)$ can be expressed as:

$$u(t) = \kappa \left\{ \frac{\lambda s(t)}{s(t)} \right\} \quad (11)$$

The signal $s(t)$ can be expressed in the form of amplitude and phase, that is $s(t) = A(t)e^{j\theta}$, $A(t)$, and $\theta(t)$ are the amplitude and phase of $s(t)$ respectively, and both are differentiable functions. Substituting into the formula can get:

$$u(t) = \kappa \left\{ \frac{\lambda s(t)}{s(t)} \right\} = \kappa \left\{ \frac{\cos \alpha * t * s(t) + \sin \alpha * \frac{-jds(t)}{dt}}{s(t)} \right\} \quad (12)$$

The signal form transmitted by the integrated radar communication system can be expressed as:

$$r(t) = d(t)s(t) = d(t)\text{rect}\left(\frac{t}{T}\right)e^{j\omega_b t} \quad (13)$$

Regarding the time domain of the single-frequency sinusoidal signal transmitted continuously, the time and frequency of the signal are not related, so that the time delay and frequency shift information in the echo reflected by the moving target cannot be obtained, and the ranging analysis cannot be performed. When the time of the signal is related to the frequency, the frequency can correspond to a specific point in time, that is, the "time scale". The time scale allows the system to accurately calculate the transmission and reception time difference and convert it into a distance, thereby reflecting the time delay in the echo. And Doppler frequency shift can also be obtained accordingly.

3 Radar Communication Integration Experiment

3.1 Subjects

This article integrates different communication methods through different methods and compares the differences between them. Perform data statistics through relevant literature, questionnaire surveys, yearbooks, etc., and use models to digitize to obtain relevant parameter values. Compare the differences between the parameters and find out the changes between the integration for signal processing and recognition.

3.2 Integrated Approach

The radar communication is integrated through the integrated waveform ambiguity function, which can be defined from the perspective of distance-velocity two-dimensional resolution and matched filter output. Assuming that the amplitudes of the two targets are the same, the received echoes of the two targets can be expressed as:

$$u(t, \theta_1) = u(t), u(t, \theta_2) = u(t + \kappa)e^{-j2\pi t} \quad (14)$$

The mean square error of the two can be expressed as

$$\varepsilon^2(\kappa, \lambda) = 2(2E) - 2\text{Re} \int_{-\infty}^{\infty} u(t)u^*(t + \kappa)e^{+2\pi t} \quad (15)$$

The ambiguity function is an effective tool for the design and analysis of radar waveforms, which is determined by the characteristics of the transmitted waveform and the filter. By analyzing the ambiguity function, the resolution and ambiguity of the radar under different design waveforms can be studied.

3.3 Determine the Evaluation Weight

The index weight is a numerical index indicating the importance and function of the index. In the indicator system of the evaluation plan, the weight of each indicator is different. Even if the indicator level is the same, the weight is different. Index weight is also called weight and is usually represented by a . It is a number greater than zero but less than 1, and the sum of the weights of all first-level indicators must be equal to 1, that is, satisfy the conditions $0 < a < 1$ and $\sum a = 1$.

3.4 Statistics

All data analysis in this article uses SPSS19.0, statistical test uses two-sided test, significance is defined as 0.05, and $p < 0.05$ is considered significant. The statistical results are displayed as mean $\pm$ standard deviation ($\bar{x} \pm SD$). When the test data complies with the normal distribution, the double-T test is used as the comparison within the group, and the independent sample P test is used as the

comparison between the groups. If the regular distribution is not sufficient, two independent samples and two related samples will be used for inspection.

4 Integrated System Signal Recognition Analysis

4.1 Development of Communication Radar

Through the methods of literature and interviews, we collected changes in various parameters of radar and communication in recent years, compared their development and changes, and studied their development trends. The changes in radar parameters are shown in Table 1:

Table 1. Radar changes in recent years

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Signal strength	3.96	4.3	4.3	4.38	4.19	3.94	4.02	4.43	3.77	4.24
Transfer speed	4.32	4.69	4.21	4.52	4.53	4.64	4.69	4.37	4.47	4.93
Transmission distance	4.92	5.15	4.81	5.31	5.01	4.96	4.7	4.98	5.04	5.44
Adaptation rate	5.25	5.81	5.17	5.11	5.96	5.42	5.83	5.58	5.61	5.94
Effectiveness	5.76	5.9	5.81	6.08	6.07	6.08	6.2	6.5	6.47	6.51

From Figure 1, we can see that in terms of various parameters of radar, although there have been some twists and turns in recent years, the overall level has shown an upward trend. The efficiency has increased from 5.76 in 2011 to 6.51 in 2020, an increase of about 13%, but The overall change in the transmission speed and the transmission distance is not large. The magnitude of change is shown in Figure 2:

Figure 2. Radar parameter changes

In order to facilitate the comparison between radar and communication, we have also made statistics on the relevant parameters of communication, as shown in Table 2:

Table 2. Recent developments in communications

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Signal strength	4.41	3.7	3.75	3.91	4.4	4.18	4.39	4.17	4.37	4.88
Transfer speed	4.33	4.86	4.5	4.7	4.95	4.82	4.91	4.24	4.33	4.79
Transmission distance	5.15	4.91	4.82	4.89	5.29	4.93	5.19	4.93	5.22	5.55
Adaptation rate	5.75	5.6	5.76	5.68	5.57	5.61	5.82	5.77	5.29	5.91
Effectiveness	5.88	5.73	6.14	6.18	5.75	6.11	5.96	6.17	6.21	6.42

From Table 2, we can see that the development trend of communication technology is similar to that of radar, showing an overall upward trend, but the development of its transmission speed and transmission distance is weaker than that of radar, and the start of radar technology is later than that of communication. The development results of the past few years have little difference in general. The changing trend of communication is shown in Figure 3:

Figure 3. Changes in communication parameters

From the figure, we can see that the change range of communication is slightly smaller than that of radar, and the change range is generally around 0.2. The change range has not been large in recent years. Among them, the detection speed has changed the most, and the increase range is around 0.35.

4.2 Different Methods to Detect Sample Differences

We detect a certain amount of cars in different ways, and compare the accuracy of the object shape after it is detected, which can effectively understand the good points of each detection method, as shown in Figure 4 and Figure 5:

Figure 4. Radar and communication detection

Figure 5. Radar communication integration

From the figure, we can clearly see that when the radar and communication are performed on the same car, the detection quality of radar and communication is not very good. The recognition quality of radar is higher than that of communication, but it is not The integrated detection method of radar communication.

4.3 Different Algorithm Recognition Situation

Through previous experiments, we have collected various parameters of radar, communication, and integrated recognition under different conditions, as shown in Table 3:

Table 3. Parameters of each communication method

	Signal strength	Transfer speed	Transmission distance	Adaptation rate	Effectiveness
Radar	1.93	2.19	2.44	2.05	2.4
Communication	1.3	1.77	2.04	2.11	2.07
Traditional integration	2.12	2.39	2.57	2.47	2.6
Waveform integration	2.43	2.42	2.73	2.6	2.75

In the same chart, we can see that after the integration of the system, the identification parameters

are much higher than those of the non-integrated system, and the transmission efficiency and transmission speed have greatly changed. However, the waveform integration system used in the experiment in this article has relevant parameters not only higher than those of radar and communication, but also due to the integration of the system using traditional methods. In order to verify the validity of the test data, we have performed multiple simulations on the system and obtained relevant data, as shown in Figure 6:

Figure 6. Different mode parameters

From the figure, we can see that after many simulation experiments, the results of the experiment can be verified. The waveform integration method used in this article can effectively improve the various capabilities of system identification. The increase rate is about 15% higher than the traditional integration rate, which can become the direction of future radar communication integration research.

5 Conclusion

At present, the integration of radar communication has been widely studied by scholars at home and abroad due to its advantages such as reducing the volume of equipment and electromagnetic interference. The integration of radar communication systems is of great significance in the civil and military fields. How to design the signal waveform of radar communication integration so that it can achieve better radar and communication performance at the same time is the difficulty in achieving integration. The basic system composition of pulse radar and continuous wave radar and the principle of speed and range measurement are described; the basic composition and principle of the communication system are given. On this basis, the problem of selecting the transmission waveform of the integrated radar communication system is brought out. The sinusoidal signal in the communication will have the nature of the chirp signal after proper transformation domain processing. This paper studies the continuous wave radar detection of integrated radar communication signals in the fractional domain. It can be applied to the integration of vehicle, shipboard, and airborne radar communication, but it is difficult to play a role in large-distance scenarios. Pulse radar can detect longer distances due to its high transmitting power, so that it can analyze the pulse radar system of the integrated signal of radar communication in the fractional domain, and broaden its application range.

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Author Contributions

All authors contributed to the study conception and design, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflict of Interests

There are no potential competing interests in our paper. And all authors have seen the manuscript and approved to submit to your journal. We confirm that the content of the manuscript has not been published or submitted for publication elsewhere.

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Na Zhang was born in Qingdao, Shandong. P.R. China, in 1982. She received the Master degree from Ocean University, P.R. China. Now, she works in Naval Aviation University. Her research interests include computational intelligence, information security and big data analysis.

E-mail: zhangn8202@163.com

Xiaomei Zhang was born in Hefei, Anhui Province, P.R. China, in 1963. She received her doctor degree of engineering from Beijing Institute of Technology, P.R. China. Now, she is working at Naval Aviation University. Her research focuses on radio communication navigation technologies and applications.

E-mail: dhzxmqd@163.com

Dong-Xiang Tao was born in Shanxi Province, China, in 1972. She received the B.S. degree from Naval electrical Engineering Academy, Nanjing, in 1994 and the M.S. degree from Air Force Engineering University, Xian, in 2004, both in electrical engineering. Her research interests include electronic testing, fault diagnosis, and signal processing.

E-mail: 2744328758@qq.com

Xiaojia Ji was born in Qingdao, Shandong, P.R. China, in 1983. He received the Master degree from Ocean University, P.R. China. Now, He works in Naval Aviation University. His research interests include computational intelligence, information security and big data analysis.

E-mail: jixiaojia2002@163.com

Figures

Figure 1

Radar operation framework

Figure 2

Radar parameter changes

Figure 3

Changes in communication parameters

Original car

Radar detection

Communication detection

Figure 4

Radar and communication detection

Original car

Radar communication integration

Figure 5

Radar communication integration

Figure 6

Different mode parameters