System of Systems Oriented Functional Level Simulation Model Design for Electronic Warfare

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Abstract. For the system of systems simulation of radar electronic warfare combat scenes in system simulation, based on the working principles of the integrated reconnaissance and jamming pod, a simulation model for the electronic warfare functional level of the reconnaissance and jamming pod has been designed. Considering the diversity of radar emission signals that need to be detected and the decision-making challenges in complex combat scenarios, different reconnaissance identification algorithms and decision-making methods have been investigated. Through simulation comparisons, the electronic warfare functional level model has been verified to be capable of simulating the different jamming effects of the reconnaissance and jamming pod on various types of radars. This model can provide support for the research of radar electronic warfare systems and tactical exercises.

Keywords: system of systems simulation； Radar Electronic Warfare； Reconnaissance and Jamming；Elec- tronic Warfare; Functional Level.

1. Introduction

In a multi-dimensional and integrated combat system, how to weaken the detection capabilities of enemy radars through advanced electronic warfare means has become one of the core issues for enhancing overall combat effectiveness. Since military operations such as the Gulf War, electronic warfare equipment has been highly valued by various countries. In the battlefield space of land, sea, air, space and power grids, the US military has constantly emphasized the importance of electromagnetic suppression [1], and electromagnetic power has become a key target for capture [2]. Therefore, the research on electronic warfare models and the simulation of electronic countermeasure processes is becoming increasingly important.

In the field of multi-element and multi-variation system combat simulation, accurately simulating the electronic countermeasure process in the battlefield space has become a crucial technology [3-7]. Traditional research on electronic countermeasure simulation mostly focuses on the study of single-function algorithms and simulation modeling, etc. In the field of electronic reconnaissance, Wu Longwen [8] demonstrated that the integration of communication, radar reconnaissance and jamming can enhance the efficiency of equipment, allowing for flexible configuration and self-adaptation in accordance with changes in combat missions. Zhou Zhijun [9] research shows that the electronic countermeasure equipment system consists of two major components: the electronic reconnaissance system and the electronic jamming system. The researchers conducted mathematical modeling of the reconnaissance model and verified the reliability, stability and applicability of the system through MATLAB simulation. Then, the researchers [9] studied the instantaneous frequency measurement model of the improved phase difference method and verified the correctness and validity of the frequency measurement model; The researchers in [10, 11] adopted dynamic clustering methods and cumulative difference histogram algorithms to sort and identify radar signals, which improved the reconnaissance accuracy.

In terms of interfering with decision-making, by applying game theory, the electronic warfare interference tactics and technical measures are combined to propose a game theory decision-making framework [12], and the decision-making criteria are reasonably expanded to improve decision-making efficiency [13], and the countermeasure effectiveness is studied [12]. In terms of intelligent decision-making for electronic interference, [14] proposed an adaptive electronic interference decision-making method, which utilizes multi-dimensional input information for adaptive thinking and decision-making. In terms of the selection of interference patterns, researchers [15] established dense false target and dexterous noise interference models and conducted simulations.

All the above studies took the electronic warfare equipment itself as the object and did not conduct design verification in the multi-element system simulation. In response to the actual needs of the electronic confrontation scenarios in the simulated system combat, there is a lack of relevant electronic warfare simulation models and experimental verification that can be interconnected and dynamically interact with other simulation models.

In response to the requirements of system simulation, the idea of parametric modeling and mechanism-based setting of behavioral models is adopted to design an electronic combat power level simulation model suitable for the scalable simulation platform (XSimStudio). Based on the framework of the electronic countermeasure simulation system of the system [16], a simulation model of electronic combat power level integrating reconnaissance and jamming was designed. This model consists of two parts: the reconnaissance model and the jamming model. It can achieve reconnaissance, sorting, and threat judgment of the target radar radiation signal, and make corresponding jamming decisions based on the judgment results, simulating the process of information update and jamming release of electronic warfare equipment reconnaissance and interception under different combat scenarios.

The innovation points of this paper lie in: 1) For the electronic countermeasure scenario of system simulation, an electronic warfare simulation model that supports initial parameter setting and has complete functions has been designed and constructed; 2) A simple and scalable electronic countermeasure strategy has been developed, which can adjust the interference strategy in real time according to the status of the radiation source and signal parameters. 3) Electronic countermeasure simulation tests were conducted in combination with the scalable simulation platform to verify the effectiveness and adaptability of the model in different combat scenarios.

2. Design concept

2.1 System design Concept

There are many types of electronic countermeasure equipment oriented towards the system. This paper takes the reconnaissance and jamming integrated reconnaissance and jamming pod as the object, and establishes an electronic combat power level simulation model, including the reconnaissance model and the jamming model. It mainly simulates the initial configuration of the reconnaissance and jamming pod in the system simulation, the reconnaissance and interception of radar signals, and the process and capability of jamming signal release. Among them, the reconnaissance model, through reconnaissance, sorting, measurement, etc. of the radar radiation signal, obtains pulse description word data including frequency, repetition frequency, pulse width, amplitude, direction and intra-pulse features, identifies the working status and parameters of the target radar, and provides the processed target reconnaissance information results to the interference model, which then makes interference decisions and generates corresponding interference signals. The functional level simulation process of the reconnaissance jamming procedure is shown in the following figure.

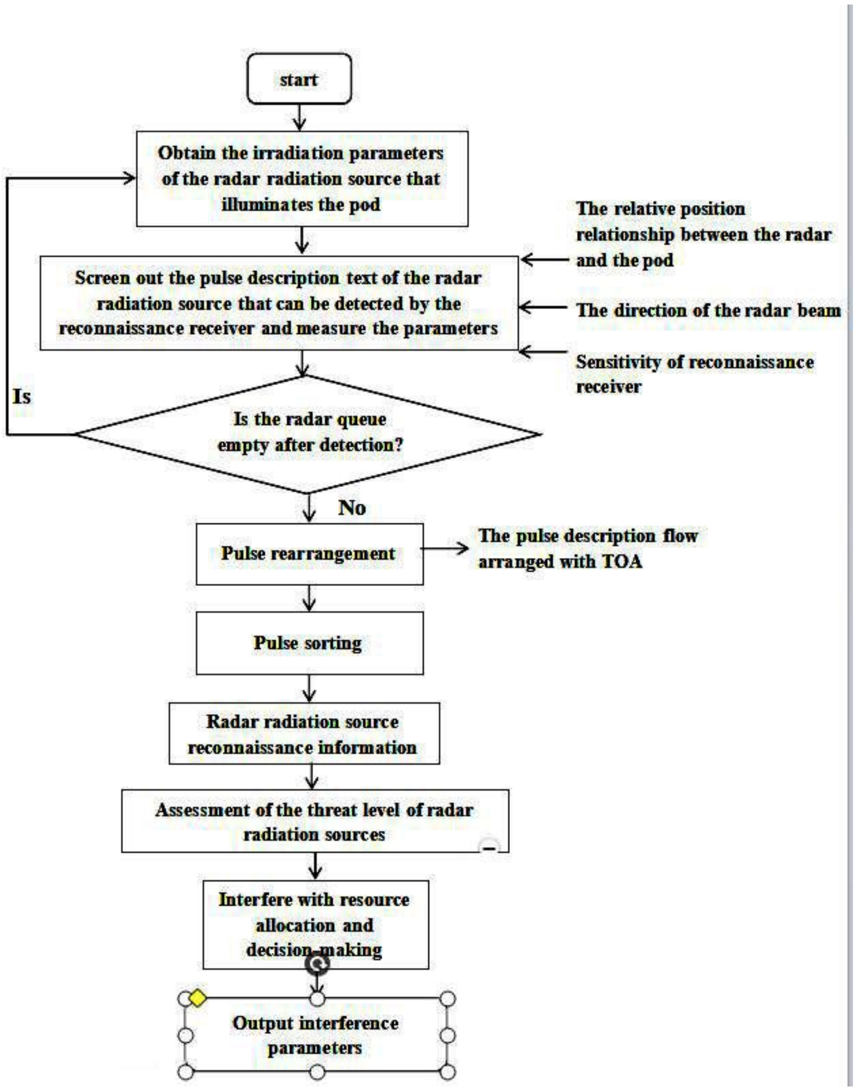

Figure 1 Workflow diagram of the functional-level simulation model of the reconnaissance jamming pod

2.2 System Composition and Functions

The design of electronic warfare models is divided into reconnaissance models and jamming models. The reconnaissance model realizes receiver simulation, signal sorting and identification simulation, and threat judgment simulation: 1) Receiver simulation: The receiver intercepts the radar radiation source signal. The radar signal that meets the interception conditions can enter the subsequent signal processing. 2) Signal sorting and identification simulation classifies the signal parameters of radar radiation sources and processes, judges and sorts them based on the correlation of the intercepted parameters. 3) The threat judgment simulation module analyzes the sorted radar signals and provides the threat level of the target based on specific evaluation criteria.

The interference model realizes the simulation of interference targets and information reception, interference decision-making simulation, and interference signal simulation: 1) Before the interference pod conducts interference, it needs to determine the interference conditions. The interference target and information reception simulation module receives the parameters of the interference target and its radar radiation source, and makes a judgment on whether the target meets the interference conditions. 2) The interference decision simulation module selects the corresponding interference decisions according to the interference style Settings at initialization, including wide and narrow band suppression interference, multiple dummy target interference, and comprehensive interference, etc. 3) The interference signal simulation module generates different types of interference signals based on interference decisions.

3. Model modeling

3.1 Reconnaissance Model

The reconnaissance model simulates the electronic reconnaissance function of the electronic reconnaissance pod for radar equipment, including the receiver simulation module, signal sorting and recognition simulation module, and threat judgment simulation module. The design of the reconnaissance model can initialize the parameter configuration of the simulation model according to its own performance. The sub-model of the reconnaissance pod first intercepts the radar radiation signals in the battlefield. The measured values of each parameter are obtained through signal parameter measurement, and the direction finding of the radiation source is carried out. The information is then packaged into radar signal radiation description characters for sorting and identification. Finally, threat judgment is carried out in combination with the threat target database to form radar radiation source reconnaissance intelligence, guiding the interference model to make interference decisions and generate radar interference signals. Its operation process is shown in the following figure:

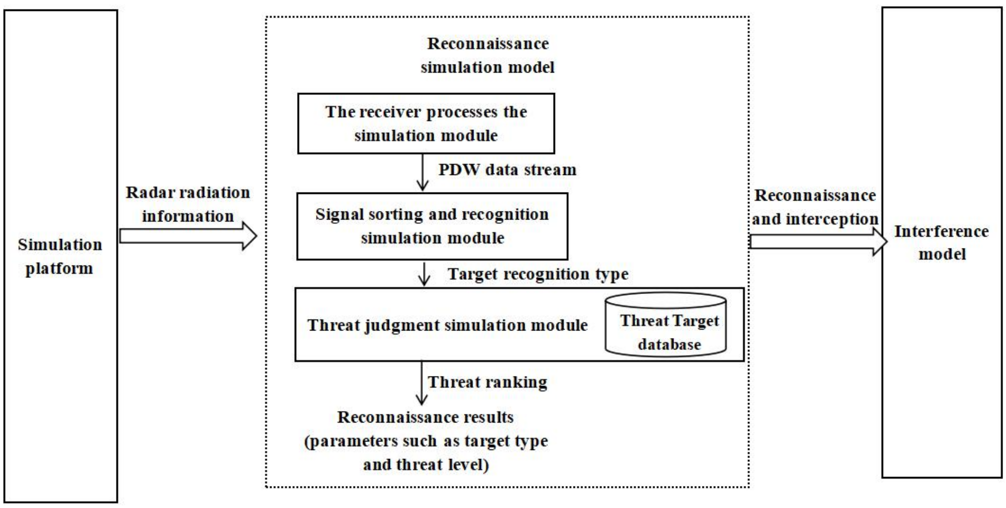

Figure 2 shows the operation process of the reconnaissance simulation model

3.1.1 Initialize configuration

To simulate the tactical capabilities of reconnaissance equipment in electronic countermeasures and ensure that working parameters can be independently set according to the capabilities of different types of reconnaissance equipment, the initial parameters for the reconnaissance model simulation are designed as follows:

Table 1 shows the initial parameter table that can be set for the reconnaissance model

sequence	Working parameters	Default reference	single
1	Maximum reconnaissance distance	200	Km
2	Reconnaissance frequency band	P band	
3	Antenna azimuth coverage range	90	degree
4	Antenna pitch coverage range	20	degree

3.1.2 Receiver Simulation

In the actual operation of the reconnaissance pod, under certain constraint conditions, the radar radiation signal can be intercepted by the receiver, and after processing, specific parameters such as the internal parameters of the radiation description word can be obtained. To effectively intercept radar signals, the reconnaissance model designed within the model needs to meet four conditions: time-domain alignment, frequency-domain alignment, spatial-domain alignment, and energy-domain alignment.

$$\begin{cases} ReconnState_{on} = 1 \\ f_{reconn} \in [f_{lower}, f_{upper}] \\ r_{Receiver-Jammer} < R_{LOS} \\ E_{Power} > S_{Receiver} \end{cases} \quad (1)$$

$\mathrm{ReconnState_{on}}$ represents the operational status of the reconnaissance pod. f_{reconn} denotes the carrier frequency of detected radar radiation signals, while f_{lower} and f_{upper} define the upper/lower boundaries of the reconnaissance frequency band. The distance between the reconnaissance pod and the radar radiation source is denoted as $r_{Receiver-Jammer}$ with R_{LOS} representing the line-of-sight distance between them. $E_{JamPower}$ and $S_{Receiver}$ correspond to the radar radiation energy and receiver sensitivity respectively. The radar signal interception process in the reconnaissance pod simulation model proceeds as follows:

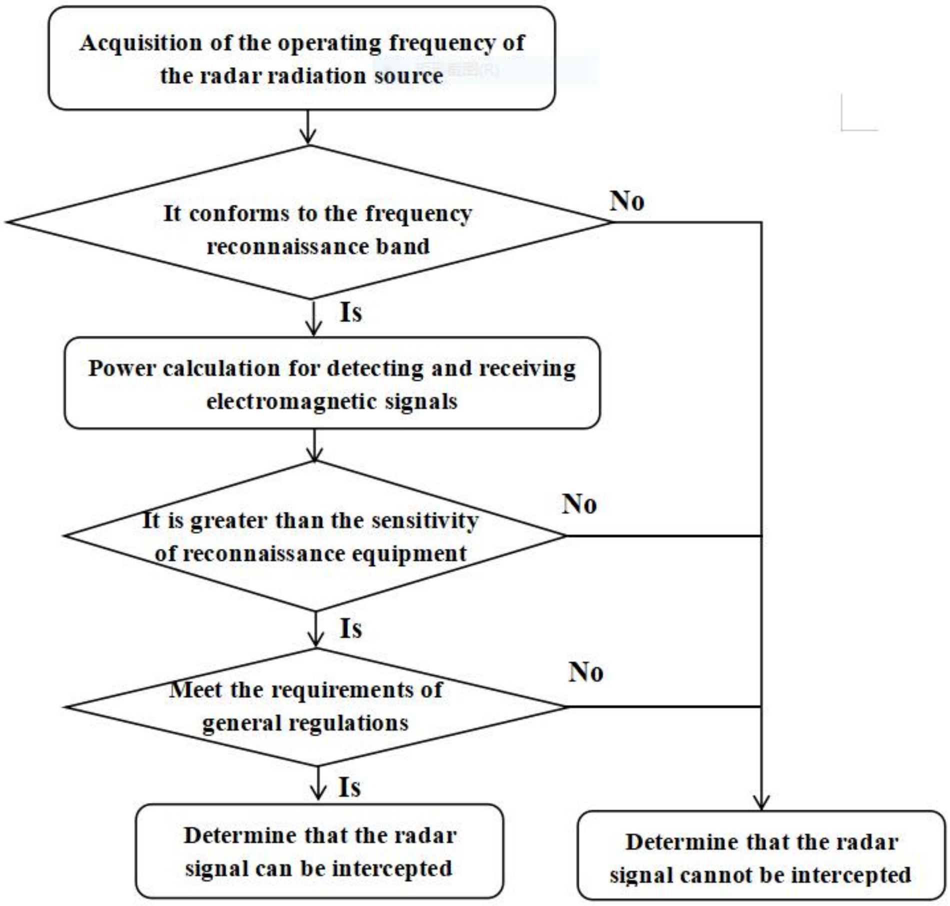

Figure 3 Simulation process of radar signal interception

Among them, T_{reconn}、θ_{reconn}、f_{reconn}、A_{reconn}、B_{reconn} are the intercepted parameters, ΔT、Δθ、Δf、ΔA、ΔB are the measurement errors, and T_{mea}、θ_{mea}、f_{mea}、A_{mea}、B_{mea} are the measured radar signal parameters. Based on them, the types of radar signals are sorted and identified.

3.1.2.1 Simulation of Signal Sorting and Recognition

Radar radiation signal sorting and recognition takes the radiation description word information of the radar signal as the characteristic parameter, and separates the multiple radar pulse signals intercepted by the reconnaissance receiver into various signal streams related to specific radiation sources. This reconnaissance model sorting and recognition simulation design assumes that in the face of complex and unknown electromagnetic scenarios, the electronic warfare model cannot use cascaded sorting algorithms, etc. based on the known empirical radar pulse signal feature library to establish a dataset for the unknown radar pulse signal stream PDW set to be sorted and recognized. Select RF (carrier frequency), PW (pulse width), DOA (Time of arrival), TOA (Angle of arrival), and PRI (pulse repetition rate) as five features Set the sample sets = (, , , , T) , = 1, ..., .

Since the number of radars contained within it cannot be predicted in advance, combined with the actual situation of the system simulation operation and the designed simulation scenarios, in most cases, there are three types of radar radiation signals: early warning radar, airborne fire control radar and ground missile weapon system guidance radar. Therefore, the Kmenas clustering algorithm can be designed and adopted in the model for the pre-sorting of unknown radars. In particular, let the number of clusters K in the algorithm be set to 3. The process is as follows:

Algorithm 1: Unknown radar signal clustering algorithm based on **K-Means**

Input: The input sample set **D**= $\{x_1, x_2, \cdots x_N\}$, the number of clusters **K**=3, and the maximum number of iterations is **M**. Randomly superposition three points $\{x_1, x_2, x_3\}$ from the clustered samples as the initial center $\{u_1, u_2, u_3\}$

Output: Sample clustering centroid $\{C_1, C_2, C_3\}$

1: **for** m = **1**→ M **do** //m represents the number of iterations.

2: $C_1 \Leftarrow \varnothing$, $C_2 \Leftarrow \varnothing$, $C_3 \Leftarrow \varnothing$ //Initialize each cluster.

3: **for** i =1,2,...,N **do** //i represents the sample set number.

4: $d_{i1} \Leftarrow ||x_i - u_1||^2$, $d_{i2} \Leftarrow ||x_i - u_2||^2$, $d_{i3} \Leftarrow ||x_i - u_3||^2$ //Calculate the Euclidean distance from x_i to the three centroids

5: **if** d_{i1}==min $\{d_{i1}, d_{i2}, d_{i3}\}$ **then**

6: $C_1 \Leftarrow C_1 \cup \{x_i\}$ //Divide x_i into the corresponding clusters

7: **else if** d_{i1}==min$\{d_{i1}, d_{i2}, d_{i3}\}$ **then**

8: $C_2 \Leftarrow C_2 \cup \{x_i\}$

9: **else**

10: $C_3 \Leftarrow C_3 \cup \{x_i\}$

11: **end if**

12: **end for**

13: $\tilde{u}_1 \leftarrow \frac{1}{|C_1|}\sum_{x \in C_1} x$, $\tilde{u}_2 \leftarrow \frac{1}{|C_2|}\sum_{\{x \in C_2} \}$ x , $\tilde{u}_3 \leftarrow \frac{1}{|C_3|}\sum_{\{x \in C_3}$ //Recalculate the centroids of each cluster

14: **if**$\{(\tilde{u}_1 == u_1)$**&&**$(\tilde{u}_2 == u_2)\}$**&&**$(\tilde{u}_3 == u_3)\}$ **then** //The centroids of each cluster remain unchanged, breaking out of the cycle

15: **Break** from line 3

16: **else**

17: $u_1 \Leftarrow \tilde{u}_1, u_2 \Leftarrow \tilde{u}_2, u_3 \Leftarrow \tilde{u}_3$ //Update the centroids of each cluster

18: **end if**

19: **end for**

20: **return** C_1, C_2, C_3 //Output result

Figure 4 Pseudo-code of unknown radar signal clustering algorithm based on K-Means

3.1.2.2 Threat Judgment Simulation

The model is based on the Analytic Hierarchy Process . Through calculation and normalization, the weights of each threat index are obtained as a set W. Let the index values of each threat evaluation factor of the radar be ( )1 5, and multiply them with W to obtain the comprehensive threat degree Z of the radar.

$$:Z = LW = \sum_{t=1}^{5} l_t \cdot \omega_t (2)$$

Z The larger the threat, the higher the threat level: 1-remote warning radar, 2-alert radar, 3-target indicator radar, 4-edge scanning and tracking radar, 5-precision tracking radar, 6-guided radar, 7-fire control radar, 8-terminal guided radar.

When the threat level calculation results of different radars are the same, the electronic warfare model considers that the radar with smaller relative distance has higher threat level.

3.2 Interference Model

The interference model simulates the electronic interference function of the interference pod on radar equipment, including three sub-modules: the interference target and information reception simulation module, the interference decision-making simulation module, and the interference signal simulation module. The interference model is initialized with parameter configuration based on the performance of the interference equipment itself. The interference target and information receiving simulation module receives the input radar radiation signal and determines whether it can interfere. The interference decision simulation module, based on the set interference strategy or target threat level, guides the interference signal simulation module to generate interference signals, which are then packaged into interference radiation information and sent to the target radar. Its operation process is shown in the following figure:

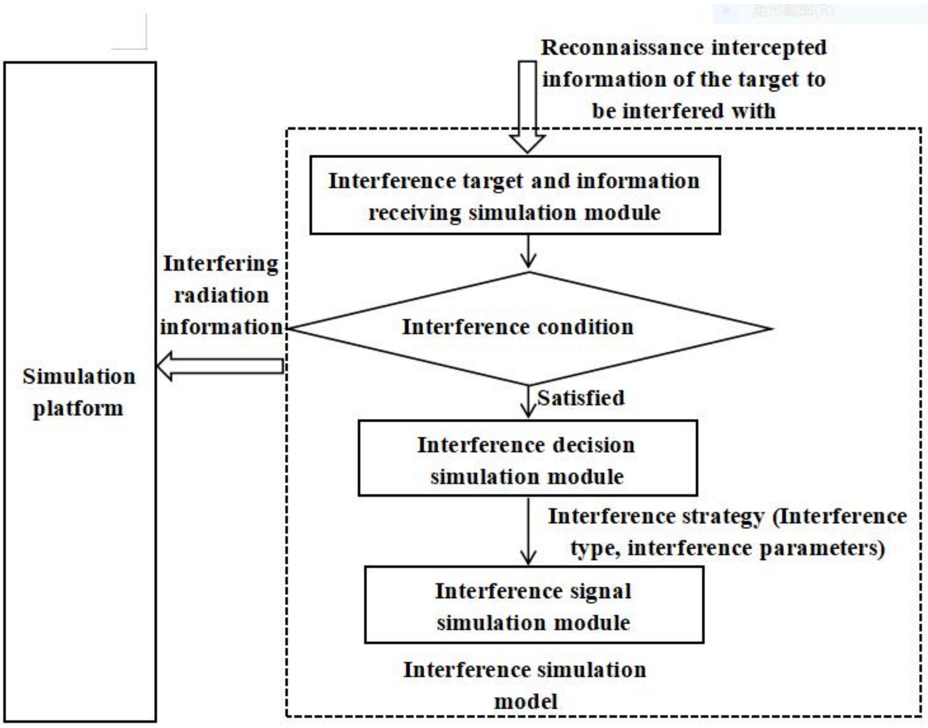

Figure 5 Flowchart of the operation of the interference model

3.2.1 Initialize configuration

Simulate the tactical capabilities of interference devices in electronic countermeasures to ensure that working parameters can be independently set according to the capabilities of different types of interference devices. The initial parameters for designing the interference model simulation are as follows:

Table 2 shows the initialization parameter table that can be set for the interference model

sequence	Working parameters	Default reference	single
1	Maximum reconnaissance distance	200	Km
2	Reconnaissance frequency band	P band	
3	Interference style	Narrowband suppression	
4	Antenna azimuth coverage range	90	degree
5	Antenna pitch coverage range	20	degree

3.2.1.1 Simulation of Interference Targets and Information Reception

After receiving the radar radiation signal, the interference model determines whether the target meets the interference conditions based on the initial configuration of the interference model. Interference conditions are classified into three types: time-domain alignment, frequency-domain alignment, and spatial-domain alignment. It is necessary to ensure that the jammer is turned on, that the carrier frequency of the target radar can be covered by the interference frequency band set in the initialization, and that the target radar is within the azimuth and pitch coverage range. Then, based on the comprehensive threat degree of the target radar input by the reconnaissance model, select the target with a higher threat degree as the priority interference object.

3.2.1.2 Interference Decision Simulation

The interference decision-making simulation module receives the radiated signals from the target radar, completes the interference decision-making according to the preset interference strategy (including interference conditions, interference patterns and parameters), generates interference instructions (including interference targets, interference patterns, parameters and interference timing), and sends them to the corresponding interference equipment.

Interference patterns can be divided into two types: manual selection and autonomous interference. The manual selection interference patterns include suppression and deception interference. For system combat scenarios, autonomous interference follows the following rules:

When the distance between the radar target and the jammer is ≥180 kilometers, select the suppression type of interference for release. It is advisable to choose broadband noise interference, with the bandwidth of the interference signal being more than five times that of the radar signal. The interference type can be selected as radio frequency noise interference or noise frequency modulation interference.

When the distance between the radar target and the jammer is less than 180km, active false target interference is selected to be released. At this time, the false targets should fill the entire pulse repetition period at a smaller interval. The false target interval can be selected as 5 to 10 times the radar resolution unit, and the dry-to-signal ratio of each false target should not be less than -3dB. When the radar is ≥160km away from the jammer, select to release noise suppression type interference and use interference signals (narrowband noise) that are sufficient to prevent the radar from tracking real targets.

When the radar is less than 160 kilometers away from the jammer, active false target spoofing jamming is selected.

3.2.1.3 Simulation of Interference Signals

The simulation model designs the interference beam width as a settable parameter, which can be adjusted from 5° to 45°. Its generation method is implemented in accordance with the Sinc function. In functional-level simulation modeling, the antenna pattern is modeled, including the modeling of how the antenna gain varies with the target azimuth and pitch angles.

$$F(a,b) = \left| \frac{\sin(\pi \frac{\alpha}{\theta_\alpha})}{\pi \frac{\alpha}{\theta_\alpha}} \right| \cdot \left| \frac{\sin(\pi \frac{\beta}{\theta_\beta})}{\pi \frac{\beta}{\theta_\beta}} \right| \quad (3)$$

Among them, α and β are respectively the azimuth and pitch deviations of the jammer's transmitting antenna from the antenna center, with the unit being radians; Youdaoplaceholder θ_α and θ_β are the antenna beam widths in the azimuth and pitch dimensions, respectively, with the unit being radians. The interference patterns in radar interference signal simulation include suppression interference patterns such as narrowband aiming noise and wideband blocking noise, as well as deception interference patterns such as range spoofing, speed spoofing, and multiple false targets.1)Simulation design of noise suppression interference signals

f_J is the center frequency of the interference signal, f_R is the center frequency of the radar signal,$\Delta f_j\Delta$ represents the bandwidth of the interference signal, and $\Delta\Delta f_r$ r represents the working band width of the radar receiver under interference

.a. Narrowband aiming noise

$$\Delta f_j \leq (2 \sim 5)\Delta f_r \quad (4)$$

b. Broadband blocking noise

$$\Delta f_j > 5\Delta f_r \quad (5)$$

2) Simulation design of deceptive Interference signals

a. Multiple false goals

The model simulates the signals of false targets, enabling the radar to detect the trajectories of false targets that do not actually exist, thus preventing it from locking onto the real targets for tracking attacks.

b. Dense false targets

For the deception and jamming of dense false targets, the jamming model simulates the combined effect of jamming and masking on the radar. It generates a series of randomly positioned false targets near the real targets. When the number is large enough, the real targets are submerged in the concentration of dense false target points, achieving an effect similar to suppressing jamming. The model designs dummy targets to fill the entire radar pulse repetition period at a smaller interval, with the interval selected as 2 to 4 times the radar resolution unit (2 to 4 times the compressed pulse width), which is equivalent to suppressing interference.

4. Design verification/Simulation analysis

4.1 System Simulation Scenario Construction

4.1.1 Initial Scene force deployment

For the system simulation system, construct the combat target forces. It includes one set of Red ground missile weapon system, one ground early warning radar, one Red interception fighter jet, one blue reconnaissance jamming aircraft and one assault fighter jet. The deployment of the intended forces is shown in the following figure (the Red fighter jets will participate in the operation after receiving the dispatch order). In this simulated combat scenario, it is assumed that the blue side's combat objective is to destroy the red side's ground missile weapon system. Simulation comparison and verification were conducted respectively under two scenarios: whether the reconnaissance jamming electronic warfare system was involved in combat or not.

Figure 6 Initial combat scene deployment diagram

4.1.2 Scene One

The reconnaissance jamming electronic warfare system shut down, and at the same time, the Red Side fighter jets were dispatched to intercept.

Figure 7 shows that the red party's early warning radar detects the blue party's intrusion target

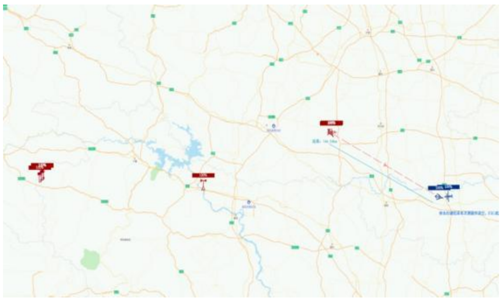

Figure 8 shows the deployment of Red fighter jets to carry out interception missions

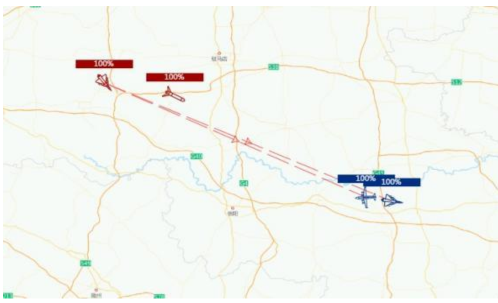

Figure 9 shows the red fighter jet locking onto the blue target and firing air-to-air bombs

Figure 10 shows the red fighter jets intercepting the dynamic formation of the blue ones

As can be seen from the figure, the red fighter jet detected the blue fighter jet. At this time, the blue fighter jet attempted to escape, increasing the distance. Subsequently, the blue reconnaissance jammer was discovered. Subsequently, the Red fighter jets continued to pursue and identified the blue target. They fired bombs to destroy it, completing the interception mission and achieving the air defense effect of the "early warning - interception" system.

4.1.3 Scene Two

The reconnaissance jamming electronic warfare system was shut down, and no Red fighter jets were dispatched to intercept it.

Figure 11 shows the Red fighter jet returning after completing its mission

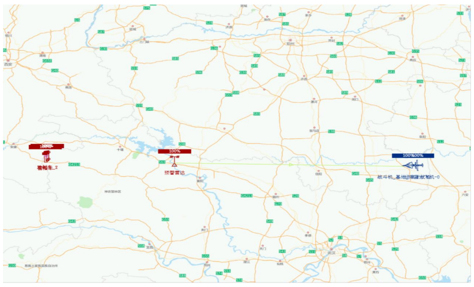

Figure 12 shows that the red party's early warning radar has detected the blue party's intrusion target

As can be seen from the simulation situation map, the ground early warning radar of the red side detected the fighter jets of the blue side and also detected the reconnaissance jamming aircraft of the blue side. Until the Blue fighter jets and reconnaissance jamming aircraft entered the detection range of the early warning radar, due to the limitations of working capacity (such as detection pitch range, etc.), the early warning radar lost its detection of the blue targets. When the blue target passed the early warning radar and gradually moved away, the early warning radar detected the blue target again.

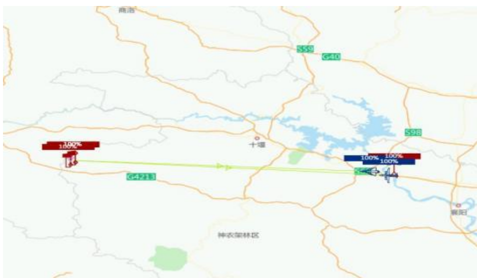

Figure 13 shows the red ground guidance radar detecting the blue target

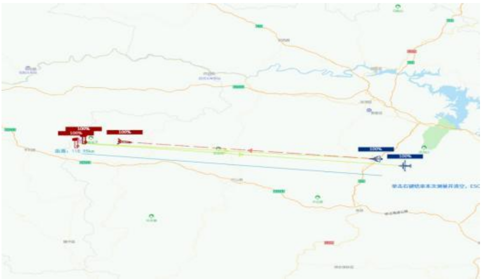

Figure 14 shows the Red side's ground missile weapon system launching anti-aircraft bombs

Figure 15 shows that the dynamic formation of the blue side was destroyed

The Red ground guidance radar detected the blue fighter jets and then spotted the blue reconnaissance jamming aircraft. The weapon system launched missiles to strike the blue targets. The missile hit the Blue fighter jets and reconnaissance jamming aircraft, achieving the air defense effect of the "early warning - strike" system.

4.1.4 Scene Three

The reconnaissance jamming electronic warfare system is turned on. In this scenario, the blue side established a coordinated electronic warfare offensive and defensive system. Facing the Red side's integrated air defense system of early warning radar, interceptor fighter jets and ground missile weapon systems, they carried out hierarchical and progressive electromagnetic suppression through the dynamic formation of reconnaissance jamming aircraft and assault fighter jets, in order to dismantle the Red side's "early warning - interception - strike" integrated air defense system Ensure that the Blue fighter jets can precisely strike the Red ground guidance system without the obstruction of air defense forces. The combat process can be divided into three stages:

1) The stage of breaking through and leading

The Blue side deployed one electronic warfare aircraft to start up and operate, flying behind the Blue fighter jet, and the two formed a dynamic formation. The reconnaissance jamming aircraft pre-confirmed the approximate position of the Red forces. After sharing the information, they went to the target area together with the fighter jets. The ground early warning radar of the red side sent detection beams, detected the aerial targets of the blue side, and sent dispatch instructions to its own fighter jets. Our fighter jets received the target instruction information and were dispatched to carry out the interception mission.

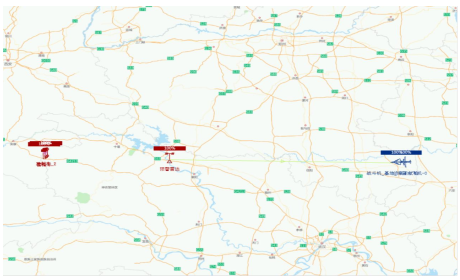

Figure 16 shows that the red party's early warning radar has detected the blue party's intrusion target

Figure 17 shows that the red side dispatched fighter jets to intercept the blue side's invading targets

As can be seen from the figure, in the early stage of the operation, the reconnaissance jamming aircraft did not detect the radiation information of the Red side's early warning radar for the time being and did not generate jamming signals. The early warning radar detected the blue side's fighter jets, and the red side dispatched interception fighter jets to conduct air search. At this point, the reconnaissance jamming aircraft can intercept the radiation information from the early warning radar and the on-board fire control radar of the Red fighter jets, and generate corresponding jamming signals. The red early warning radar is unable to continue detecting the blue target, and the red fighter jets cannot perceive or detect the blue target.

2) Coordinated breakthrough stage

The Blue fighter jets, supported by the electronic warfare system of the reconnaissance jamming aircraft, charged into the core area of the red side. When the reconnaissance jammer is turned on and in operation, the reconnaissance system is synchronously activated. Meanwhile, the reconnaissance jamming machine intercepts the radiation information from the early warning radar and the airborne fire control radar, sorts, identifies and judges the intercepted radiation signals. After the jamming system makes a decision, it generates the corresponding jamming radiation information and emits multi-band suppressed jamming signals (covering three types of bands) that can cover the intercepted radar radiation signals, thereby reducing the detection efficiency of the Red Square radar system. This caused the Red side's early warning radar to lose its target point. The Red side's interception fighter jets dispatched could not detect the invading target, achieving the effect of covering the blue side's fighter jets' advance into the Red side's central area and creating a tactical advantage window for subsequent hard damage.

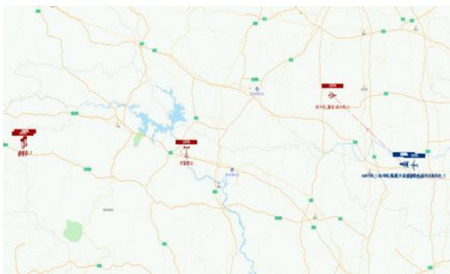

Figure 18 shows the red fighter jet sensing and detecting the blue target

Figure 19 shows that the blue side's reconnaissance jamming machine interferes with the red side's early warning radar for cover and advance

Figure 20 shows the blue formation entering the range of attack on the red ground missile weapon system

3) Precision strike stage

After breaking through the Red side's medium and long-range air defense circle, the Blue side's reconnaissance and jamming aircraft continued to suppress the Red side's ground missile weapon system's radar pointing vehicle, resulting in the ground missile weapon system being unable to search for, detect and track the Blue side's assault fighter jets and air-to-ground missiles. Ultimately, the blue combat forces were able to damage the Red ground missile weapon system under the cover of the reconnaissance jamming machine's electronic warfare system.

Figure 21 shows the blue team's combat formation to strike the red team's ground missile targets

Figure 22 shows the blue team's combat formation destroying the red team's ground missile target

4.2 Simulation Result Analysis

During the leading stage of the blue side's dynamic formation, the Blue side's fighter jets were detected, and the red side dispatched fighter jets to intercept them. After the blue side reconnaissance jammer conducted reconnaissance, interception, sorting and identification, it obtained the radiation information from the early warning radar and the airborne fire control radar. Then, the threat level is obtained through threat judgment (airborne fire control radar: 7, early warning radar: 1), and the interference model makes interference decisions and releases interference signals.

After the Blue dynamic formation broke through the long-range air defense circle, the reconnaissance jamming aircraft continued to conduct reconnaissance jamming. The radar beam emitted by the ground-guided weapon system's radar steering vehicle shone on the fighter jets in the blue dynamic formation. The radar radiation information of the radar command vehicle intercepted by the reconnaissance jammer was used for threat assessment. It was found that the threat level of the radar radiation signal of the radar command vehicle was 6, and it was determined to be a weapon system guidance radar. As the dynamic formation of the blue side shortens the ground guidance distance of the red side, the jamming system, based on the reconnaissance results, adopts a method of first launching suppression jamming and then launching multiple dummy target jamming for cover.

The simulation results show that the radar detection vehicle detected a total of four targets, including a fake target made by the reconnaissance jamming mechanism and a real Blue fighter jet. The real target was submerged among the fake ones, unable to form a stable and traceable track. The radar detection information was chaotic and it was unable to lock onto the blue fighter jet and form a missile launch command. Eventually, it was destroyed by the blue fighter jet. Based on the above simulation results, through the reconnaissance and identification of the radar radiation information of the radar command vehicle, the reconnaissance jammer emits multiple false targets to interfere, providing cover for the blue assault aircraft to precisely strike the red weapon system and complete the combat mission.

5. Summary and Outlook

This paper designs the electronic combat function level model in the simulation of the electronic countermeasure system, and constructs the functional level simulation model of electronic warfare equipment from the aspects of reconnaissance system and jamming system. Moreover, this model is a universal one, supporting the initialization of parameter configuration. By modifying the parameters, models of reconnaissance and jamming equipment with different working capabilities can be obtained. The simulation results show that the designed reconnaissance jamming functional-level simulation model can detect the radiated signals of early warning radars, fire control radars, guidance radars, etc., and generate suppression and deception jamming at different operational planning stages. It has efficient real-time computing capabilities and dynamic update capabilities, and can support the rapid decision-making and response of electronic countermeasure system simulation planning. Subsequently, based on this simulation model, in-depth research can be conducted on the modular implementation algorithms and methods of reconnaissance and jamming to enhance the sorting identification and threat judgment capabilities. Intelligent decision-making algorithms can be introduced to adaptively generate appropriate jamming radiation signals, as well as research on human-in-the-loop confrontation, to support operators in conducting combat simulation training. Provide electronic warfare model support elements for the research of radar electronic countermeasure systems and combat exercises.

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