Research and Implementation of Emitter Threat Assessment Based on Distributed Simulation

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***Abstract*—The threat degree of radiation source detected by fighter in penetration operation is the main reference for fighter to make the next operation plan. The research objective of this project is to evaluate the threat of radiation sources detected by aircraft ,based on distributed interactive simulation technology, the system modeling of aircraft flight detection data and ground radar detection warning in distributed system is realized by building a variety of simulation modules such as ground radar model, aircraft radar model, coordinate transformation model and threat level evaluation model, the simulation environment system of airborne emitter warning is completed. In this experimental environment, through simulation, the real-time calculation of the threat factor of the aircraft radiation source can be carried out, and then the dynamic threat assessment of the radiation source target can be realized.**

Keywords-Distributed Simulation; Radar Detection; Coordinate Transformation; Threat Assessment

I. INTRODUCTION

In the modern battlefield, it is very important to accurately evaluate the target's electromagnetic interference and threat level, and reasonably formulate the fighter combat strategy, literature [1] points out that it is very important to improve the survival probability of fighter in battlefield. Literature [2] says that in fact, it is a very ideal state to calculate according to the real battlefield data. In the experimental stage of the algorithm, we need to simulate the flight data and radar data of the fighter in the battlefield through the computer simulation technology, and then carry out the level evaluation according to the simulation data to get the order of the threat coefficient, so as to provide reliable reference data for the formulation of the fighter combat strategy [3-5].

The research of this subject is divided into two modules, one is the realization of simulation model in distributed simulation system, which is realized by MFC in vs environment, the other is Qt development environment, which uses C + + language to realize the assessment of emitter threat.

In the flight trajectory of aircraft in simulated battlefield and the detection of ground radar, the data of combat object in battlefield is simulated by constructing distributed simulation system. Secondly, the modeling and simulation system of Emitter Threat Level Evaluation in penetration operation is constructed. The system can realize the evaluation of the threat level coefficient of the aircraft to the emitter. The data of the aircraft and the data of each emitter obtained from the data source simulation files are transformed through coordinates and the modeling of aircraft warning radar, The data ranking of the threat coefficient of radiation source to aircraft can be obtained. The interface of the system can see the position of the aircraft in the geographical coordinate system, the attitude angle of the aircraft and the corresponding dashboard display of each attitude angle. At the same time, it can intuitively see the position of the radiation source relative to the aircraft, and the data of the radiation source sorted according to the threat level. This is conducive to the fighter in the battlefield real-time combat strategy, improve the survival probability of the fighter in the battlefield has important practical significance.

II. SIMULATION SYSTEM

A. Construction target

With the development of modern electronic battlefield technology, more and more advanced weapons are put in. The addition of early warning radar, radar jamming, missile attack and other radiation sources leads to the short-term survival probability of fighters in the battlefield [6]. In order to make fighter play an efficient and long-term role in the modern electronic battlefield, it is necessary to calculate the real-time data of fighter and radar, and formulate a reasonable and efficient strategy for fighter [7]. Therefore, in order to ensure the survival probability of the fighter, we use simulation technology to simulate the flight trajectory of the fighter in the battlefield, as well as the data of the radar. Through the propulsion of the unit step, we can get the real-time data of the aircraft and the radar in each step, and then get the real-time data [8].

According to the simulation data, through coordinate transformation and level evaluation model, the order of the threat coefficient of aircraft radiation source at the current time is obtained.

B. The composition of simulation system

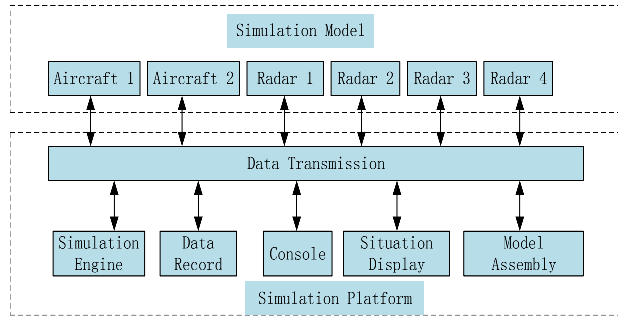

Figure 1. Simulation System Framework

As shown in Figure 1, the simulation system is mainly composed of two parts: simulation model and simulation platform.

The simulation model mainly includes aircraft 1, aircraft 2, radar 1, radar 2, radar 3, radar 4 and other combat objects.

The simulation platform mainly includes simulation engine, data recording, situation display, model assembly, console and so on.

III. SIMULATION MODEL OF SIMULATION SYSTEM

The main models used in the simulation system are aircraft radar model, ground radar model, coordinate transformation model, threat level assessment model, and the results of aircraft operation are displayed.

A. Detection model of ground early warning radar and aircraft radar

The key to the establishment of ground radar model is the radar detection range equation, that is, the calculation of echo signal power. The simplified formula of ground early warning radar and aircraft radar is as follows:

The detection equation of ground early warning radar is as follows：

$$P_{gr} = (P_{gt} G_{gt} \sigma \lambda^2) / (4\pi)^3 R^4 \qquad (1)$$

Aircraft radar detection equation:

$$P_r = (P_{gt} G_{gt} G_r \lambda^2) / (4R)^2 \qquad (2)$$

The meaning of each parameter in the formula is shown in Table 1.

TABLE I. PARAMETERS OF GROUND TO AIR RADAR DETECTION EQUATION

Parameter	Explain
P_{gt}	Transmitter power of ground early warning radar
G_{gt}	Antenna gain of ground early warning radar
G_r	Aircraft radar antenna gain
λ	wavelength
σ	Radar cross section of target
R	Distance between ground early warning radar and aircraft
P_{gr}	Target echo power received by ground early warning radar
P_r	Signal power of ground early warning radar received by aircraft radar

Assuming that the parameters and sensitivities of a certain type of ground early warning radar and aircraft radar $P_{\min}$ are known, when the ground early warning radar and aircraft situation have been determined, the sum is calculated by the distance between them and the values of other known parameters to judge whether the ground early warning radar and aircraft radar can detect each other and decide whether to alarm. Generally, the detection range of ground early warning radar is wider than that of aircraft radar. The comparison of discrimination results is shown in Table2.

TABLE II. COMPARISON OF GROUND TO AIR RADAR TARGET JUDGMENT RESULTS

Condition	Discriminant results
$P_{gr} < P_{\min 地}$	Not detected
$P_{gr} >= P_{\min 地}$	Detected
$P_r < P_{\min 空}$	Not detected
$P_r >= P_{\min 空}$	Detected

B. Coordinate transformation model

Coordinate transformation is an important step in this modeling and simulation. According to the position of the aircraft itself in the geographical coordinate system and the position of the radiation source in the geographical coordinate system, the following coordinate systems should be transformed: geographical coordinate system, geocentric coordinate system, North East coordinate system and carrier coordinate system. The purpose of coordinate transformation is to determine the position of radar in the aircraft coordinate system with the aircraft as the origin. The final position is expressed by azimuth and elevation. These two values are important parameters for the subsequent evaluation of radiation source level.

1) Coordinate transformation

a) Coordinate transformation process

The simulation system obtains the original data of the aircraft and the radiation source in the geographic coordinate system, and then transfers the obtained data into the geocentric rectangular coordinate system and the north sky East coordinate system, and then enters the carrier rectangular coordinate system according to the attitude angle of the read aircraft. After the conversion, the position of the radiation source in the carrier coordinate system can be obtained, thus the azimuth and height angle of the radiation source can be obtained. The flow chart of coordinate transformation is shown in Figure 2

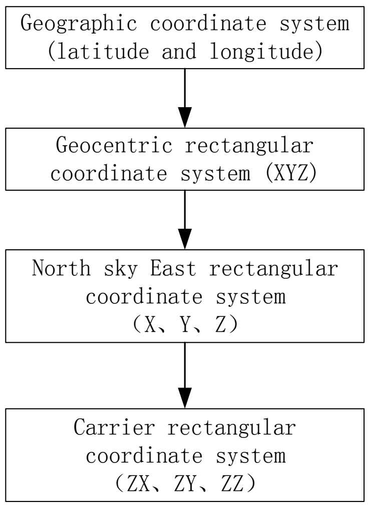

Figure 2. Flow chart of coordinate transformation

b) Geographic coordinate system to geocentric rectangular coordinate system

Latitude is the latitude in the geographical coordinate system, longitude is the longitude in the geographical coordinate system, altitude is the height in the geographical coordinate system. Longitude and latitude need to be converted into radians before entering the conversion formula, as shown below:

Convert latitude to radians:

$$B = \text{latitude} * \pi / 180 \tag{3}$$

Convert longitude to radian:

$$L = longitude * \pi / 180 \tag{4}$$

The height is the directly used H (in meters).

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} (\mathrm{N+H})*\cos\mathrm{B}*\cos\mathrm{L} \\ (\mathrm{N+H})*\cos\mathrm{B}*\sin\mathrm{L} \\ (\mathrm{N}*(1-e^2)+\mathrm{H})*\sin\mathrm{B} \end{bmatrix} \tag{5}$$

As shown below, the corresponding relationship between geographic coordinate system and geocentric rectangular coordinate system is as follows,

c) Geocentric coordinate system to North Tiandong coordinate system

The B'and L' used here are the same as the above explanation. This coordinate system is based on the geocentric coordinate system. After rotating twice, the conversion of the geocentric coordinate system to the North Tian dong coordinate system can be completed. The following is the formula used in the conversion:

$$B' = \begin{bmatrix} 0 & \sin B & \cos B \\ 1 & 0 & 0 \\ 0 & -\cos B & \sin B \end{bmatrix} \tag{6}$$

$$L' = \begin{bmatrix} -\sin\mathrm{L} & \cos\mathrm{L} & 0 \\ -\cos\mathrm{L} & -\sin\mathrm{L} & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{7}$$

$$C = B' * L' = \begin{bmatrix} -\sin B\cos L & -\sin B\sin\mathrm{L} & \cos\mathrm{B} \\ -\sin B & \cos L & 0 \\ \cos B\cos L & \cos B\sin L & \sin B \end{bmatrix} \tag{8}$$

According to the linear transformation corresponding to the matrix, the corresponding relationship between geocentric rectangular coordinate system and North Tian dong rectangular coordinate system can be obtained as follows：

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = C * \begin{bmatrix} \mathrm{x} \\ \mathrm{y} \\ \mathrm{z} \end{bmatrix} \tag{9}$$

d) North Tiandong rectangular coordinate system transfer machine rectangular coordinate system

The north sky East rectangular coordinate system rotates around three axes, and the rotation angle is the attitude angle of the aircraft. According to the transformation of the following formula, the carrier coordinate system can be obtained:

$$\begin{bmatrix} ZX \\ ZY \\ ZZ \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} * \begin{bmatrix} \cos\theta_g * \cos\theta_P - \sin\theta_P * \sin\theta_f * \sin\theta_g & \sin\theta_P * \cos\theta_f + \sin\theta_f * \cos\theta_P * \sin\theta_g & -\cos\theta_f * \sin\theta_g \\ -\cos\theta_f * \sin\theta_P & \cos\theta_P * \cos\theta_f & \sin\theta_f \\ \cos\theta_P * \sin\theta_g + \sin\theta_P * \sin\theta_f * \cos\theta_g & \sin\theta_g * \sin\theta_P - \sin\theta_f * \cos\theta_P * \cos\theta_g & \cos\theta_f * \cos\theta_g \end{bmatrix} \quad (10)$$

1) Ancient forest method

In the ancient forest method, the first step is to compare the importance of all the threat factors from top to bottom, and then quantify the importance of each threat factor, and give its specific value according to experience, so it needs a strong working experience to evaluate, which also determines the quality of the whole evaluation model. The second step is to standardize the importance of threat factors. The process of standardization is to deduce the standardized importance of each factor from bottom to top based on the standardized importance of the last item as 1. The third step is to divide the importance of the standardized threat factor by the sum of the importance of all the standardized threat factors to get the weight of the threat factor [9-10].

Here, the method to determine the weight in Table 3 is described:

a) The importance of threat factor, set as Rj, is determined according to the experience value in the battlefield.

*b) The importance of standardization, set as kJ, is based on the last item, which is set as 1 and calculated from bottom to top Kj=Kj+1*Rj.*

$$Ci = Ki / \sum Ki \quad (11)$$

c) Weight, set to CI, use the formula 11 to get.

TABLE III. WEIGHT VALUE DETERMINATION METHOD

Serial Number	Threat Factor	Importance of Threat Factors Rj	Importance of Standardization Kj	Weight Ci
1	type	4	24	0.72727
2	frequency	3	6	0.18181
3	distance	2	2	0.06061
4	position	1	1	0.03031
total			33	1.000

2) Membership function of each threat factor of radiation source

Membership function of emitter type: in electronic battlefield, the type of target emitter increases the threat degree to a great extent.

$$U(x1)=\begin{cases}0.1\ , & x1=Rader\\ 0.9\ , & x1=Missile\end{cases} \quad (12)$$

Membership function of emitter frequency: in electronic battlefield, when the frequency of emitter increases, the threat coefficient increases.

$$U(x2)=\begin{cases}0\ , & 0<=x2<=1000\\ 1-e^{-5(x2-0.1)^2}, & x2>1000\end{cases} \quad (13)$$

Membership function of emitter distance: with the increase of the distance, the detection threat of the emitter to the fighter is reduced. For the missile, the navigation distance of the missile is increased, and the warning time of the fighter is prolonged, thus the attack threat to the fighter is reduced. At the same time, with the increase of distance, it increases the probability of the enemy's miss, and further reduces the threat.

$$U(x3)=\begin{cases}1, & x3<=30\\ 0.5-0.5*\sin(\frac{\pi}{200-30})*(\frac{x3-(200+30)}{2}), & 30<x3<=200\\ 0, & x3>200\end{cases} \quad (14)$$

Membership function of emitter azimuth: in the process of flight, the direction pointed by the aircraft head is the Direction with the greatest threat degree, and its threat angle has a certain threat degree in azimuth and high and low angles.

$$U(x4)=\begin{cases}1\ , & -15^0<=x4<=15^0\\ 0.8, & 170^0<=x4<=190^0\\ 0.5, & 80^0<=x4<=100^0 或 260^0<=x4<=280^0\\ 0.3, & \text{other}\end{cases} \quad (15)$$

$$W_i=\sum_{i=1}^{n} C_i * U(x_i) \quad (16)$$

Then, formula 16 is used, where n represents the sequence number of the radiation source, CI is the weight of the radiation source threat factor, u (XI) represents the membership function of the radiation source factor, and W represents the threat degree of the radiation source. There are many methods for radiation source grade evaluation, such as AHP [12], fuzzy comprehensive evaluation [13] and fuzzy multi-attribute evaluation [14]. In this paper, the ancient forest method is used to estimate the weight of several threat factors, and then the threat degree is calculated by membership function. Here, the emitter level evaluation modeling and simulation is based on the position of the aircraft itself and the geographical location and frequency of the emitter transmitted by the parameters of the function.

IV. SIMULATION PLATFORM

The simulation tool is composed of a series of modules as follows:

1) Model assembly: the assembly function module of the model ensures that the assembly of the combat object model can be completed quickly and run on the simulation platform;

2) Simulation engine: it is a functional module of simulation engine that parses the XML file of the planned combat object, and drives the combat simulation according to the combat scenario; In the XML file, the initialization data of aircraft and radar as well as the coordinate points and flight speed of aircraft trajectory are stored. Users can change the state of combat objects in the battlefield by changing the data in XML, and then get different data.

3) Situation display: the battlefield situation display function module of the combat scene can realize the intuitive display of the battlefield situation.

4) Data recording: the function module of recording and playing back the simulation process data can record the simulation process data, which is convenient for post analysis and can be played back;

5) Console: the console includes data records. At the same time, after the user clicks the start, pause, continue and stop buttons on the console, MFC completes the operations that the server and client need to perform through the message mapping mechanism [11.15]. Each federate of the simulation system calls the corresponding function to process the data through the message type of the received data, so as to ensure the synchronization of the simulation system [16]. In this simulation system, distributed simulation is used for data transmission, which provides data transmission between simulation engine and model, simplifies the data interface of simulation model, and facilitates the implementation of distributed simulation.

In order to ensure that the simulation time step of the aircraft crew is consistent during the flight, the simulation step is set to 0.01 seconds. The simulator console defines a variable current time with an initial value of 0, which is used to record how many rounds of data the two aircraft have sent. The console defines a class to manage the data of each aircraft, and stores the data in the container. There is a member variable sending time to record the number of flight data sent by each aircraft, and the initial value is 0. When the two aircraft have completed the flight, the console will add one to the current time of the variable, and then check before sending the propulsion command. If the current time is greater than the sending time, it is allowed to send the propulsion command to the aircraft, and add one to the sending time of the corresponding member variable that manages the aircraft. Due to the network delay, there is a problem of how fast the packets of the two aircraft arrive at the console. The aircraft thread with fast packet arrival can sleep for a period of time and detect alternately until the packets of the other two aircraft arrive, and then proceed to the next simulation step. The promotion process of synchronization mechanism is shown in Figure 3.

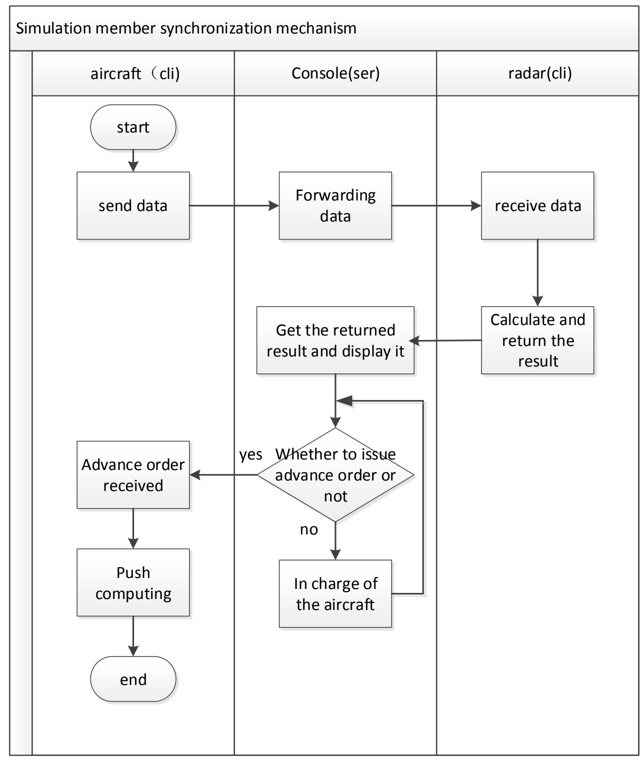

Figure 3. Flow chart of synchronous propulsion mechanism

The simulation platform uses XML technology to complete the initialization of simulation system parameters and aircraft scenario setting; The console is responsible for the start, pause, continue and stop of the simulation system, for the forwarding of relevant data between ground to air radars, and for the display and data collection of mutual detection results of ground to air radars during aircraft flight; Ground early warning radar and aircraft warning radar are responsible for target detection and warning.

V. THREAT LEVEL ASSESSMENT SYSTEM

According to the data obtained from the simulation platform, the radiation source threat level assessment system is established in the QT environment. When the system starts to run, firstly, the data source is simulated to read the file, and the data is read by line according to the time stamp, and the data at the same time is stored in the container. Secondly, the angle between the radiation source and the aircraft is obtained according to the data in the container through the coordinate transformation model, Then, according to the ancient forest method to determine the weight, and membership function to determine the threat coefficient, namely the emitter threat level evaluation model, and then sort, finally load these data into the interface to display. As shown in Figure 4:

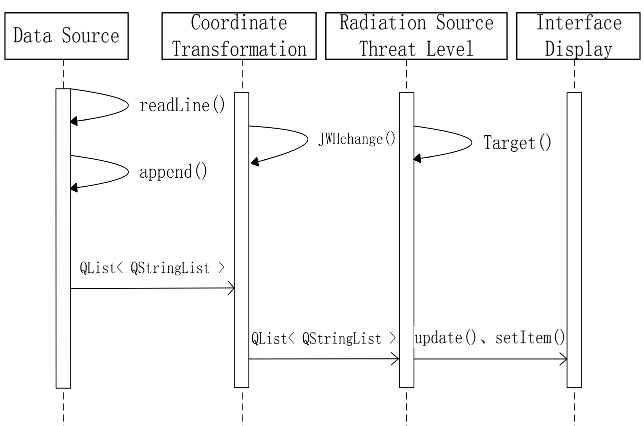

Figure 4. System sequence diagram

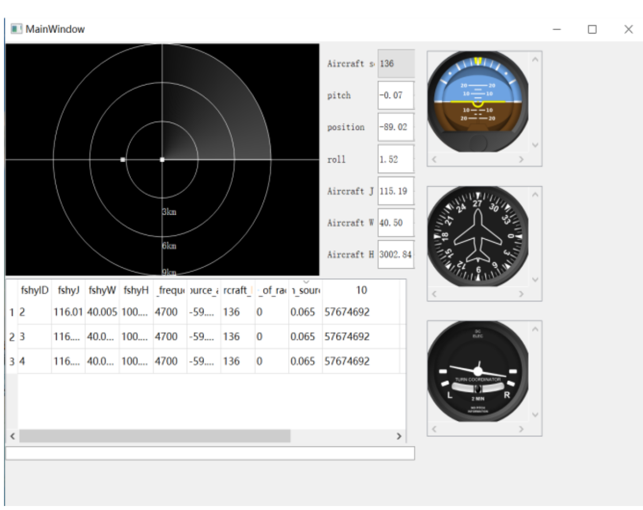

Figure 5. Operation result diagram

The final result of emitter level evaluation based on distributed simulation is the ranking of the emitters detected by the aircraft at a certain time. The final rendering is shown in Figure 5.On the left side is the attitude angle data of the aircraft, and from top to bottom are the pitch angle, heading angle, roll angle, as well as the longitude, dimension and altitude of the aircraft; The scannin image takes the aircraf as the origin and marks the radiation source in the form of points in the two-dimensional coordinate system; The table below is the data of radiation sources, including the longitude, dimension, altitude, frequency, radar area density, aircraft ID, radar working status of radiation sources and the threat degree of radiation sources. The ranking of threat degree can provide effective reference for the formulation of aircraft penetration operation strategy and improve the survival probability of aircraft.

VI. Conclusion

In the modern electronic battlefield, it is impossible for fighter to penetrate without being found. When the enemy's air defense missiles and radars begin to fight, how the fighter to penetrate requires the fighter to have a real-time and overall grasp of the data of various radiation sources in the whole battlefield, and have an accurate grasp of the threat of radiation sources, so as to formulate a reasonable and comprehensive plan in the battlefield Some strategies against anti-aircraft such as the flight route that can be realized. Based on the research and implementation of emitter level evaluation in distributed simulation, this paper constructs a simulation system. By simulating the trajectory and state of the combat object in a typical battlefield, the data obtained by step is obtained by comprehensively considering the influence factors of time, space and electromagnetic environment in the battlefield, The order of the threat degree of the fighter's radiation source at a certain time in the battlefield is obtained, which provides a powerful reference for the fighter's next route or attack strategy.

REFERENCES

[1] Ma Hong, bu Wei. Electronic warfare simulation system for operational requirement verification. Electronic information countermeasure technology. 2019. (3). 40-43.

[2] Chen Yongguang, Shao Guopei, Zhang Shunjian. Research on combat effectiveness of air defense weapon in EW simulation system. Firepower and command and control. 1999. (4). 73-78.

[3] Kong Depei, Zhu Yifan, Yang Feng. Function simulation of radar detection. Computer simulation. 2003. (8). 119-122.

[4] Zhao Xingyun, Li Hua, Tang Xuefei. Computer simulation of radar reconnaissance equipment function simulation mathematical model. 2006. (4). 5

[5] Locker J. An introduction to the internet networking environment and SIMNET/DIS[R]. TechnicalReport, M onteney:NavalPostgraduates school, 1993.

[6] SikoraJ.Advanceddistributed(ADS)/distributedinteracti vesimulation(DIS)[M]. Phalanx.1- 995.

[7] Zhu Guanlan, Han Yuanjie, Jiang fangting. Research on radiation source threat level assessment technology. Military communication. 2007.23 (262): 10-12.

[8] Sumanta Kumar Das, Modeling Intelligent Decision-Making Command and Control Ag- ents:An Application to Air Defense.Institute for Systems Studies and Analyses, Delhi, India. 2014.

[9] Mark Allen Weiss. Data Structures and Algorithm Analysis in C++[M].3rded. Upper Saddle River, New J ersey: Prentice Hall, 2006.

[10] Liu Bingyan, Liu Xiangwei, Hao Chengmin, et al. Research on threat level evaluation model of electronic air defense target. Ship electronic countermeasures. 2014. 37 (1): 57-61.

[11] Lu Wenzhou. Qt5 development and examples. Beijing: Electronic Industry Press, 2014.

[12] Zhao Xingchen, Wu Jun, Xu Yunshan, et al. Radiation source threat level assessment based on analytic hierarchy process. Modern defense technology. 2012.40 (5): 35-40.

[13] Chen Yawen, Xia Weijie, Wu Lianhui, et al. Assessment of radiation source threat level based on AHP fuzzy comprehensive evaluation method. Modern electronic technology. 2014.37 (19): 21-24.

[14] Jiang Ning, Hu Wei Li, sun Ao. Fuzzy multi attribute method for determining threat level of radiation source. Acta Ordnance Engineering Sinica. 2004.25 (1): 56-59.

[15] Huo Yafei. Practical solution of QT and QT quick development. Beijing: Beijing University of Aeronautics and Astronautics Press. 2012.

[16] Yang Wanhai. Radar system modeling and simulation [M]. Xi'an: Xi'an University of Electronic Science and technology. 2007.