Research on Simulation Technology of Infrared Missile Battle Scene

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Abstract. To provide a battle scene for the semi-physical simulation of infrared missile. Picked the main factors of infrared radiation processing, calculated target and background’s temperature, atmospheric radiation transmission, infrared smoke interference. Performed simulation calculation for ship-type target under battle scene and analyzed the simulation results. Provides support for test design.

1. Introduce
The infrared missile battle scene is a complex geophysical environment [1]. The infrared missile detects the infrared band radiation of the target and background and generates infrared image [2]. The information processing system performs target detection to complete the guidance [3]. The infrared missile battle scene simulation is to infield the missile simulation of the battle scenarios faced, providing target and background radiation data or image data[4] for missile performance test verification.

The simulation of the infrared missile battle scene mainly involves [5] the calculation of target and background’s temperature, infrared radiation [6], atmospheric radiation transmission [7] and infrared artificial interference [8]. The temperature of target and background is affected by a variety of factors such as [9] environment, weather, and the atmosphere. During the radiant energy passes through the atmosphere to reach missile, it is necessary to consider the attenuation effect of the atmosphere and the superimposed effect of the atmospheric thermal radiation; if the interference of the released smoke and infrared decoy shells[10] is considered, smoke shielding and decoy shells need to be added. Interference calculation. But the response function model of the detector can be disregarded in semi-physical simulations.

2. Infrared Scene Simulation Technology

2.1. Target and Background’s Temperature and Radiation
(1) Ocean background temperature and radiation calculation
Water wave motion is a complex random process. In oceanography, power spectrum models are usually used to simulate geometric models of water surface, such as Cox-Munk spectrum model and PM spectrum model. Sea surface temperature is closely related to seasonal climate and geographical conditions, and water bodies can be used as research objects. Considering the endothermic or exothermic heat of the water body, a thermal equilibrium equation for the water body is established, and the equilibrium equation is expressed by temperature. Solving the equation, the temperature is obtained. Assume that the temperature distribution of the water is only a parameter of depth. When analyzing the heat exchange on the surface of the water, a small thin layer on the water surface is used as the object. According to the law of conservation of energy, the heat flow into the small thin layer is
including the downward radiation of the sun and the instant broadcast radiation of the sky, the emitted energy includes the thermal radiation of the water surface, the convective heat transfer between surface and atmosphere, the latent heat lost by the evaporation of surface, and the heat exchange between the lower surface of the small layer and the lower layer. And thermal diffusion due to eddy current, the heat balance equation of the water surface can be expressed as:

\[ q_{\text{sun}} + q_{\text{sky}} + q_{\text{conv}} + q_{\text{lm}} + q_{\text{f}} + q_{\text{dif}} + q_{\text{evaq}} = \Delta q_{\text{sur}} \]  

(1)

\[ \Delta q_{\text{sur}} = \rho c \delta \frac{dT}{dt} \]  

(2)

Where \( q_{\text{sun}}, q_{\text{sky}}, q_{\text{conv}}, q_{\text{lm}}, q_{\text{f}}, q_{\text{dif}}, q_{\text{evaq}} \) are the sun, sky, frictional heat, water surface, external convective heat transfer, internal heat transfer, and surface radiation absorbed by the outer surface, and absorb heat for the small thin layer. Each term in the formula can be expressed by a formula containing the temperature of the water body, and the temperature field distribution of water can be obtained by solving the equation. The total infrared radiation leaving water surface is composed of self-radiation, reflection of solar radiation, and the radiation reflection of surrounding scenery, where solar radiation produces a highlight effect on water surface. The brightness of infrared radiation leaving the water surface can be expressed as:

\[ L_{\text{tot}} = \varepsilon L_{\text{lm}} + \rho L_i + L_{\text{spec}} \]  

(3)

\[ \varepsilon = 0.98 \times [1 - (1 - \cos \theta)^5] \]  

(4)

where \( \varepsilon \) is the effective emissivity of water surface considering the angle of the line of sight and the water surface normal angle.

(2) Calculation of target temperature and radiation

The ship target have power equipment, the heating part has a higher temperature than surrounding background, the intensity of infrared radiation is much higher than background. However, the heat exchange and thermal effects occurring in the heating part and the surrounding area are relatively complicated and need to be viewed. In different states, the infrared radiation characteristics are significantly different. For anchored ships, surface temperature is evenly distributed, \( \Delta T \) between different parts are different, sun-illuminated surface is high, and the shaded surface is low. When the ship is under navigation, key parts radiate increased and the radiation characteristics are obvious. The calculation process of the ship's temperature field distribution as follows: a) Establish the ship's surroundings model, mesh it, and establish the product element set for the temperature field. b) Determine the boundary conditions for the temperature field calculation and perform the temperature field calculation,

\[ \frac{\partial^2 T}{\partial x_1^2} + \frac{\partial^2 T}{\partial x_2^2} + \frac{\partial^2 T}{\partial x_3^2} + \frac{q}{\kappa} = \frac{1}{a} \frac{\partial T}{\partial t} \]  

(5)

Factors affecting the temperature distribution of the target include solar radiation, convective heat transfer between target and surrounding air, and internal radiation from the heat source of the power unit. The boundary conditions on each boundary plane are calculated based on the target state and surrounding environmental factors. Solve the above equation to obtain the temperature distribution of ship.

2.2 Atmospheric Radiation Transmission

The influence of the atmosphere is mainly reflected in the attenuation of the background radiant energy of the target passing through the atmosphere, it can be expressed as:

\[ T(\lambda) = \exp(-L\beta_{\text{exp}}) \]  

(6)

Where \( L \) is the distance and \( \beta_{\text{exp}} \) is the atmospheric extinction coefficient. When atmospheric emissions are not considered, radiation obtained at a distance \( l \) from a known radiation source \( I \) is

\[ I(\lambda, l) = I(\lambda, 0) \exp[-\int_0^l \beta(\lambda, l) \, dl] \]  

(7)
Affected factors of atmospheric radiation transmission come from many aspects, which can be expressed by the basic equations of atmospheric radiation transmission, but the solution process is complicated and tedious, and specific atmospheric calculation software can be directly used for specific calculations. As long as the composition of the atmosphere and its height distribution and input parameters such as season, time, geographical location, and observation geometry are known, atmospheric output parameters such as atmospheric transmittance, atmospheric distance radiation, and atmospheric background radiation that affect infrared imaging can be calculated. The atmospheric output parameters designed by infrared imaging simulation include direct solar radiation reaching the sea surface, atmospheric path radiation, atmospheric transmittance, and atmospheric thermal scattered radiation. The calculation process usually includes the following aspects: (a) Calculation of atmospheric spectral transmittance. (b) Calculation of direct solar irradiance. (c) Calculation of atmospheric scattered radiation. (d) Atmospheric thermal radiation.

When professional software is used to calculate atmospheric radiation transmission, the input parameters involved are slightly different according to the calculated output terms. According to the input parameters, the atmospheric transmittance, direct solar radiation, atmospheric distance radiation, and atmospheric background radiation can be calculated.

### 2.3 Infrared Smoke Interference
Smoke changes thermal radiation transmission including: (1) radiation attenuation caused by absorption and scattering during direct transmission; (2) scattering and radiance from the smoke itself. The smoke interference needs to consider the smoke interference effect, and calculate the smoke transmittance and the radiation and scattering of the smoke. The smoke transmittance depends on the composition of the smoke and the smoke concentration, as well as the shape distribution and mass extinction coefficient of the smoke. smoke transmittance can be expressed by optical thickness

\[
\beta(\lambda, s) = \int_{0}^{\tau} \alpha(\lambda; s')c(s') ds' = \alpha_{OBS}CL_{OBS}
\]

\[
\tau_{OBS} = \exp(-\alpha_{OBS}CL_{OBS})
\]

Where \(\alpha_{OBS}\)is the mass extinction coefficient, which is an inherent attribute determined by the composition, size, and shape of the particle group that constitutes the smoke; \(C\) is the density of the smoke; \(L_{OBS}\) is the length of the smoke path on the line of sight; and \(CL_{OBS}\)is the total mass concentration integrated by the line of sight.

In addition to the radiation emitted by smoke, it also includes radiation scattering from the outside of the smoke, such as solar radiation, sky background radiation, and radiation from other radiation sources in the battlefield environment. Considering radiation scattering from external light sources, smoke radiation can be expressed as:

\[
I(\lambda, r; \mu, \Phi) = I(\lambda) + \int_{0}^{\tau} J(\lambda, r'; \mu, \Phi) \exp[-(\tau - \tau')]d\tau'
\]

Where \(\mu, \Phi\) is the zenith angle and azimuth of the propagation path; \(\tau\) is the optical thickness; \(J(\lambda, r'; \mu, \Phi)\)is the optical source function of multi-scattering from all directions and all point sources along the propagation path.

### 2.4 Viewed Infrared Radiation
The radiation reaching the guided missile mainly includes direct solar radiation, infrared radiation of the ground scene itself, solar radiation reflected by the object, radiation from the atmospheric path, and environmental radiation. The proportion of radiation emitted by different bands before entering the guided missile is different. To facilitate the calculation, consideration should be given to the emphasis, which should be appropriately simplified.

The infrared radiation of an object consists of two parts: self-radiation and reflection from external radiation. Without considering the reflection characteristics of the surface mirror, the apparent infrared radiation leaving the surface of the object can be expressed as
\[ L_{\text{up}} = \int_{\lambda_1}^{\lambda_2} \epsilon(\lambda, T)L_e(\lambda, T)\,d\lambda + \sum_{j=1}^{M} \int_{\lambda_1}^{\lambda_2} \rho(\lambda, T)H_j \,d\lambda \]  
(11)

The infrared radiation transmission characteristics of the infrared radiation reaching the guided missile mainly include ground attenuation and atmospheric distance radiation after atmospheric attenuation, that is,

\[ L_{\text{vis}} = \int_{\lambda_1}^{\lambda_2} \tau_{\text{ATM}} \epsilon(\lambda, T)L_e(\lambda, T)\,d\lambda + \int_{\lambda_1}^{\lambda_2} \tau_{\text{ATM}} \rho(\lambda, T)L_e(\lambda, T, T_{\text{AE}})\,d\lambda + L_{\text{ATM}} \]  
(12)

The ambient infrared radiation reflected from the surface of an object is

\[ L_e(\lambda, T_{\text{AE}}) = \sum_{j=1}^{M} \int_{\lambda_1}^{\lambda_2} \rho(\lambda, T)H_j \,d\lambda \]  
(13)

If there is smoke interference, the extinction and radiation of the smoke need to be considered.

\[ L_{\text{vis}} = \tau_{\text{smoke}} \cdot \int_{\lambda_1}^{\lambda_2} \tau_{\text{ATM}} \epsilon(\lambda, T)L_e(\lambda, T)\,d\lambda + \int_{\lambda_1}^{\lambda_2} \tau_{\text{ATM}} \rho(\lambda, T)L_e(\lambda, T, T_{\text{AE}})\,d\lambda \]  
+ \overset{\lambda_2}{\int_{\lambda_1}} L_{\text{ATM}} + L_{\text{smoke}} \]  
(14)

When analyzing the target background temperature difference transmission, the apparent temperature difference formula needs to be used

\[ \Delta T = \frac{\int_{\lambda_1}^{\lambda_2} [M(\lambda, T_{\text{t}}) - M(\lambda, T_{\text{b}})]\,d\lambda}{\int_{\lambda_1}^{\lambda_2} \frac{\partial T}{\partial \lambda} \,d\lambda} \]  
(15)

where \( M(\lambda, T_{\text{t}}), M(\lambda, T_{\text{b}}) \) is the outgoing radiation of the target and the background, respectively.

3. Simulation Analysis

During the course of the missile's flight towards the target, the distance is continuously approaching, and the target is prominent in the field of view. The resulting image is a collection of sequence images based on the time axis. Capture a momentary imaging, that is, the signal transmission process of the radiation from the target background to the infrared imaging system at a specific time and a specific distance, and analyze the impact of various links and factors of the battle scene on the imaging guidance from the mechanism. The wave-guided missile in the simulation entered at noon on a certain day in April and started the search, tracking, and locking process in the set infrared battle scene. It mainly records the missile image, working status information, infrared simulation information, and statistics missile search, Locking distance and other indicators, analyze the impact of target background temperature, weather conditions, and other factors on detection performance.

The infrared image observed by the guided missile is a digital sample of the target background radiation converging to the focal plane through the optical system and undergoing photoelectric conversion. Real imaging includes complex physical effects such as optical jitter of the atmosphere, geometric distortion of the optical system, diffraction, and sampling of the sensor system. In the simulation calculation, the imaging simplification is regarded as the geometric projection of the scene on the imaging focal plane, and the infrared radiation that reaches the missile from any point in the field of view is calculated according to the projection relationship. Assume that the target and the background are uniform black bodies, and ignore the differences in the surface of the object, and treat them as ideal black bodies with the same emissivity and reflectance everywhere. The infrared scene parameter setting and calculation result data are shown in the table.

| Table 1. Infrared scene parameter |
|----------------------------------|
| Environment settings: 2019/4/5/13:30 |
| position | 42.01°/121.42° | altitude | 200m | Band | 3.7-4.8μm |
| mode | Mid-latitude summer | Atmospheric condition | VIS | 23km | Relative humidity | 25% |
| Wind speed | 2m/s | Air temperature | 24°C | Surface pressure | 1.7446E4Pa |
| No. | Parameter                                      | Calculated              |
|-----|------------------------------------------------|-------------------------|
| 1   | Radiation off the background surface           | 5.6(W·m⁻²·s·r⁻¹)       |
| 2   | Radiation from target surface                  | 12.72(W·m⁻²·s·r⁻¹)     |
| 3   | Atmospheric transmittance                       | 0.40                    |
| 4   | Atmospheric range radiation                    | 1(W·m⁻²·s·r⁻¹)          |
| 5   | Apparent radiation target                      | 6.08(W·m⁻²·s·r⁻¹)       |
| 6   | Apparent radiation background                   | 3.24(W·m⁻²·s·r⁻¹)       |
| 7   | Inherent ΔT                                    | 20K                     |
| 8   | Apparent ΔT                                    | 24K                     |
| 9   | Viewed ΔT                                      | 9.5K                    |

### 4. Conclusion

Infrared missile battle scene simulation technology simulates the missile battle scene in the infield. Under the premise of saving cost and efficiency, it can accelerate the missile performance detection and verification to the maximum extent. In the simulated environment, the experiment can be repeated many times, taking missile guidance process in specific environment as an example, simulation calculation of important parameters in infrared scene, experimental analysis of simulation of infrared missile battle scene. Provide technical support for the evaluation of infrared missile infield test.

### 5. References

[1] Fan Jin-xiang, Chai Juan-fang. Review of Offensive and Defensive Simulation Techniques for Infrared Imaging Guided Missiles in Complex Battlefield Environments[J]. Proceedings of the 2016 Infrared and Remote Sensing Technology and Application Symposium and Interdisciplinary Forum, 2016.

[2] Yu Kun, Guo Biao, Cong Ming-yu. Infrared imaging modeling and image simulation of space target edge detection background[J]. Infrared and Laser Engineering, 2019(9),48(9):942-946.

[3] Li Wenhao, Liu Chaohui, Mu You, et al. Modeling and research of infrared characteristics of space target based on radiation dissipation[J]. Infrared and Laser Engineering, 2017, 46(6):0604003.

[4] Wang Yan-kui, Wu Gen-shui, Ji Shuang. Research on Simulation Modeling of Seeker's Variable Tracking Point Infrared Image[J]. Infrared Technology, 2018, 40(12):54-59.

[5] Zhang Fang, Qi Lin-lin, Ge Jie ect. Effect of Typical-aerosol and Visibility on the Mid- and Far-Infrared Light-wave Transmission in the Standard Atmosphere[J]. Infrared Technology, 2016,38(12):1047-1051.

[6] Li Hui, Wu Jun-hui, Chen Qian-rong. Boundary capability and consistency of infrared seeker injection closed-loop test[J]. Optical Precision Engineering, 2016, 24(4):913-921.

[7] Li Peng-cheng, Yang Suo-chang, Li Bao-chen. Research on Modeling and Simulation of Infrared Imaging Seeker Servo System[J]. Modern Defense Technology, 2015, 43(3).

[8] Gao Wen-jing, Wang Ya-li, Yin Zhi-yong ect. Influence analysis of atmospheric transmittance on operating range of infrared system[J]. Laser and Infrared, 2016(7),46(7):832-836.

[9] Fang Tian-tian. Design and Modeling and Simulation of Infrared Seeker Control System[D]. Harbin Engineering University, 2016.

[10] Lian Wen-hao, Wang Yong-jie, Yang Xiao-long ect. Design of light waves atmospheric transmittance model based on MODTRAN[J]. Laser and Infrared, 2016,46(12):1531-1536.