Chapter 7
3D Scene Modeling and Real-Time Infrared Simulation Technology Based on Artificial Intelligence Algorithm

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Abstract With the continuous advancement of information technology and the increasing demand for real-time infrared simulation, establishing a high-performance real-time infrared simulation system is the primary task of battlefield information support system and the key factor to determine the outcome of the war. 3D infrared scene simulation technology is widely used in military-oriented fields such as performance test and evaluation of weapon imaging system, infrared remote sensing and mapping. In this chapter, driven by Artificial Intelligence (AI) technology, an infrared 3D scene modeling algorithm based on improved Convolutional Neural Network (CNN) is proposed. The calculation of material infrared image, the establishment of infrared image database and the real-time infrared scene modeling based on global 3D scene are preliminarily realized, and its modeling performance is simulated through experiments. The results show that after many iterations, the accuracy of the improved CNN is better than that of the traditional CNN, reaching more than 95%, and the error is also significantly reduced. The infrared image generated by this method is basically consistent with the real infrared image, which provides an effective way to prepare infrared reference map in real time.

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7.1 Introduction

3D target recognition is of great practical significance in the military. At present, the research methods of 3D target recognition can be roughly divided into three types: based on visual computing theory, active vision and model-based recognition. Because the weapon system developed by using infrared imaging technology has a series of advantages, such as working day and night, strong anti-interference ability, high accuracy and strong flexibility, it has attracted the attention of all countries and developed vigorously [1]. Infrared imaging simulation technology has been widely used in military fields such as night navigation, optical remote sensing, precise guidance and target detection [2]. Based on the theoretical model of infrared radiation calculation, the infrared simulation technology using computer graphics and virtual reality technology has the main characteristics of flexibility, high precision, strong anti-interference ability and improving the efficiency of imaging system [3]. Because infrared imaging equipment is expensive and the production process is particularly complicated, obtaining different infrared target characteristics is a key problem to be solved urgently in infrared imaging technology [4]. In fact, although a lot of resources are invested, the captured infrared images still cannot meet the requirements of different scenes and weather conditions. Because the field test can get the real evaluation results, it is an accurate method to complete the dynamic test, but because of its shortcomings such as high cost, long cycle, high risk and large resource consumption, it cannot meet the technical research and progress requirements in the process of weapon development, thus restricting the effectiveness of its evaluation [5, 6].

With the development of computer simulation technology, infrared images under different conditions can be obtained by simulation-based methods, and the testing and verification of infrared equipment can be completed on the computer platform. The principle of infrared band imaging is different from that of visible band imaging. In infrared imaging, not only the sun-related radiation but also the thermal radiation of the object itself needs to be considered [7]. Based on the theory of visual computing, it is needed to reconstruct the 3D shape of an object by using stereoscopic images, image sequences or clues such as shadows and textures. In the future digital battlefield, whether it is military training, tactical drills, effectiveness evaluation or tactical demonstration, real-time infrared simulation scenes may be needed to support and guarantee [8]. Designing a purely digital or semi-physical computer photoelectric virtual simulation framework, establishing an infrared battlefield environment, simulating the movement of targets, interference, background, detectors and the dynamic change process of radiation energy, and constructing a radiation transmission model that conforms to the infrared imaging principle have become an indispensable and important content in the development of infrared imaging weapon systems [9]. The basic calculation model of target recognition has the characteristics of purpose-driven or purpose-guided. In this article, driven by AI technology, an infrared 3D scene modeling algorithm based on improved CNN is proposed, and the calculation of material infrared image, the establishment of infrared image database and the real-time infrared scene modeling based on global 3D scenes are preliminarily realized.

7.2 Methodology

7.2.1 Application of AI in Infrared Image Processing

Any object in nature, such as the atmosphere, land or buildings, will have the characteristics of emitting, absorbing or transmitting electromagnetic waves when the temperature is higher than absolute zero. At present, most infrared scene simulations are based on local scene modeling, which is limited in scope, difficult to expand, single in experimental data and lacking of sufficient demonstration [10]. In infrared scene simulation, the color imbalance of visible light remote sensing images reduces the accuracy of automatic segmentation and classification of ground objects, and the temperature of the same ground object will jump when the temperature is modulated by the short-wave reflectivity characteristics of visible light remote sensing images, which needs to be dealt with. The system provides an indirect, efficient and unified interface for high-level geographic scheduling and display, and supports massive infrared scene data superposition and scheduling [11]. In the experiment, the processed infrared model is organized into a target scene and superimposed on the designated position on the earth. Infrared imaging link refers to the process that ground objects receive external radiation, and at the same time superimpose their own thermal radiation through self-reflection, and transmit upwards. After atmospheric attenuation, the infrared imaging system converts the radiation into digital images before reaching the lens of the infrared imaging system.

When obtaining visible light remote sensing images, whether for satellite images or aerial images, due to the influence of external atmosphere and illumination, the inhomogeneity of optical lenses, shooting time and other factors, the inhomogeneity of brightness and contrast of ground objects in images and the hue difference between images will be caused. In an image sequence, the scale of the target can't remain the same, maybe the target will go from far to near, from near to far, or both. In the process of going from far to near, the target becomes larger and the resolution becomes clearer, and the information becomes more and more abundant. Obviously, the contribution of the target to recognition is different under different scale resolution conditions [12]. Before constructing the full-link mathematical model of infrared imaging, it is needed to analyze the transmission path of energy between light source, atmosphere, scene and infrared imaging system, and consider the influence of various factors on infrared imaging, so as to make the constructed model more accurate and help to improve the fidelity of infrared simulation images.

Targets with small scale and large resolution provide more information, so they make great contributions to recognition; however, the target with large scale and small resolution provides less information, so it makes little contribution to recognition. In order to remove the phenomenon of uneven illumination, contrast and color difference in visible remote sensing images and realize the consistency of the overall color of the images, it is needed to balance the colors of the images. Infrared imaging link refers to the process that ground objects receive external radiation, and at the same time, they superimpose their own thermal radiation through self-reflection, transmit upwards, and reach the infrared imaging system through atmospheric attenuation, and the infrared imaging system converts the radiation into digital images.

7.2.2 3D Scene Modeling Algorithm of Infrared Image

With the increasing scale of the scene and the refinement of the model, the proportion of visible patches in all patches will gradually decrease at a specific point of view. At this time, most invisible parts in the scene can be cut out by visibility calculation, and redundant calculation of invisible parts can be avoided in the subsequent radiation field energy calculation. Image even light and color processing is a processing method to solve the color imbalance of visible light remote sensing images, so that the processed images can not only meet the subjective evaluation of human vision, but also achieve the effects of consistent brightness, moderate contrast and consistent tone between images, and optimize the mosaic effect of remote sensing images [13]. It is impossible for the posture of 3D target to change suddenly in a short time. In order to apply this dynamic constraint of target movement to target recognition, it is needed to correctly estimate the posture of the target at each moment, and then find the corresponding transfer matrix value, that is, the transfer cost between adjacent frames, according to the space transfer matrix of the target characteristic view. By increasing the high-frequency components in the image in frequency domain, strengthening the reflection information, reducing the low-frequency components in the image and weakening the ambient illumination information, the dynamic range of the brightness of the image can be reduced and the contrast degree can be enhanced, so as to achieve the effect of enhancing the characteristic information while weakening the illumination change. The dynamic fusion method of infrared image features based on CNN is shown in Fig. 7.1.

It is assumed that the scene of the dual-band infrared image is a rectangular bin $d_S = d_x d_y$ perpendicular to the main optical axis of the lens, its radiation brightness is described by L, and its observation distance is described by l, and its image $d_{S'}$ is also a rectangular bin. If the optical system satisfies the Abbe sine condition, then:

$$n_h \sin\theta_0 = n'h' \sin\theta_0' \tag{7.1}$$

n and n' are used to describe the refractive index of infrared image scene space and corresponding image space. h and h' are used to describe the height and image height

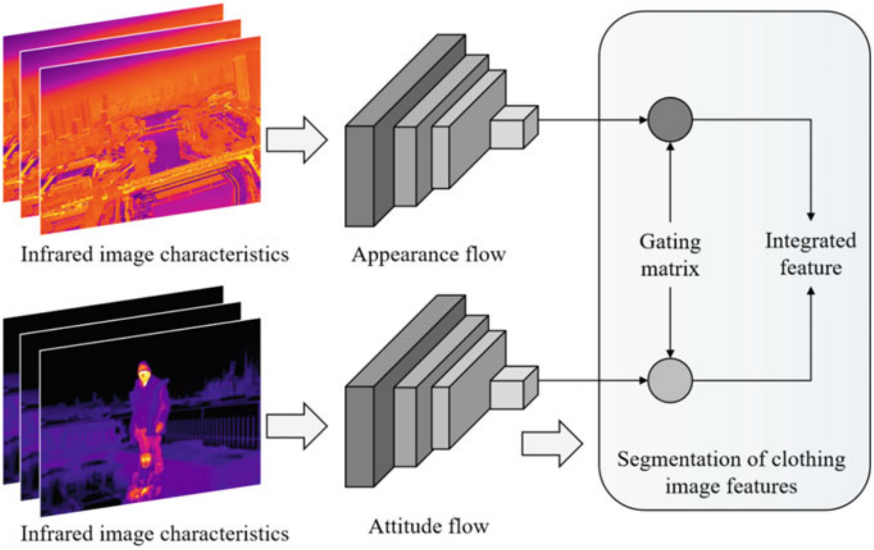

Fig. 7.1 Dynamic fusion of infrared image features

of infrared scenes. θ_0 and θ_0' are used to describe the angle between the infrared image scene space and the corresponding image space ray and the main optical axis.

The radiation power radiated from d_S to the solid corner element of the entrance pupil d_Ω $\left(d_\Omega = \sin\theta_0 d_{\theta_0} d_\phi\right)$ of the optical system can be obtained by the following formula:

$$d_P = L(\theta, \phi) d_x d_y \sin\theta_0 \cos\theta_0 d_{\theta_0} d_\phi \tag{7.2}$$

If the system has no loss in the whole process, the power needs to be calculated from the solid corner element d_Ω' $\left(d_\Omega' = \sin\theta_0' d_{\theta_0}' d_\phi'\right)$ and the image space element $d_{S'} = d_{x'} d_{y'}$.

Select a segment of the original polygon, and set the straight line on one side of the ideal rectangle corresponding to this segment as $\Delta t p_t u_t(y)$. If the straight line is set parallel to the corresponding edge of the minimum area circumscribed rectangle, the straight line is divided into $1 + \Delta t u_t\left(y'\right)$. The formula for the sum of square errors between the segment and the straight line in the original polygon is:

$$P_{t+\Delta t} = p_t + \Delta t p_t u_t(y) \tag{7.3}$$

$$P_{t+\Delta t} = p_t(1 + \Delta t u_t(y)) + p_t\left(1 + \Delta t u_t\left(y'\right)\right) \tag{7.4}$$

$P_{t+\Delta t}$ finds the first-order partial derivative of y. When the first-order partial derivative is 0, the error is the smallest, so:

$$s_{t+\Delta t}(y) = \frac{p_{t+\Delta t}}{P_{t+\Delta t}} = \frac{p_t + \Delta t p_t(y)}{p_t(1 + \Delta t u_t(y)) + p_t(1 + \Delta t u_t(y'))} \tag{7.5}$$

$$s_{t+\Delta t}(y) = \frac{p_{t+\Delta t}}{P_{t+\Delta t}} = \frac{s_t(y)(1 + \Delta t u_t(y))}{s_t(y)(1 + \Delta t u_t(y)) + s_t(y')(1 + \Delta t u_t(y'))} \tag{7.6}$$

The fitted straight line equation for this segment is:

$$s_{t+\Delta t}(y) - s_t(y) = s_t(y)\frac{\Delta t u_t(y) - \Delta t \overline{u}_t^p}{1 + \Delta t u_t} \tag{7.7}$$

The fitting linear equations of the other three segments are obtained by the same method.

After geometric modeling of 3D scene, it is needed to build texture database and material database for it, and realize the correlation between geometric model and texture database and material database, so as to facilitate the calculation of subsequent radiation energy field modules. The information of the target is related to the resolution of the image, that is, the scale. Under the condition of no zoom, the more pixels the target image occupies, that is, the higher the resolution, the smaller the scale and the richer the information. In the subsequent radiation energy field calculation module, the geometric data and material parameters of ground objects need to be used, so it is needed to consider the correlation between material parameters of objects and geometric models. It is needed to design a reasonable data organization structure in order to speed up the search of material parameters and improve the speed of system simulation in the subsequent calculation of radiation field energy.

7.3 Result Analysis and Discussion

Because of the variety of geography, climate, weather, materials and other factors in infrared scene simulation, in order to meet the real-time requirements, it is needed to establish an infrared mapping image database with different materials. The database adopts relational database structure, and is classified according to the characteristics of images. The classification principle is to divide according to infrared band, surface temperature and atmospheric environment. When designing a 3D real-time simulation platform for dual-band infrared image scene, the design of software is very important. In order to reduce the difficulty of platform development, it is needed to analyze the software functions, gather related functions together, and divide the software functions by module encapsulation. The 3D real-time simulation platform of dual-band infrared image scene should not only use the input interface to collect the infrared image of the infrared detector, but also use the output interface to play back the infrared image to the integrated processor. The simulation operating system is Windows 11, the processor is Core i7 13700k, the graphics card is RTX 3060Ti, the memory is 16 GB, and the hard disk capacity is 1 TB. By assigning a material number to each pixel in the texture map, a texture map with the same size as the texture map is generated. The accuracy of image feature extraction of different algorithms in infrared image 3D modeling is shown in Figs. 7.2 and 7.3.

The final conclusion of the model depends on the sample set to some extent. Therefore, the selection of sample sampling technology is very important for successfully establishing a suitable infrared image feature extraction model. The parameters such as simulation time, aerosol mode and visibility are obtained, and then the atmospheric elements database is queried to obtain solar irradiance and atmospheric downward

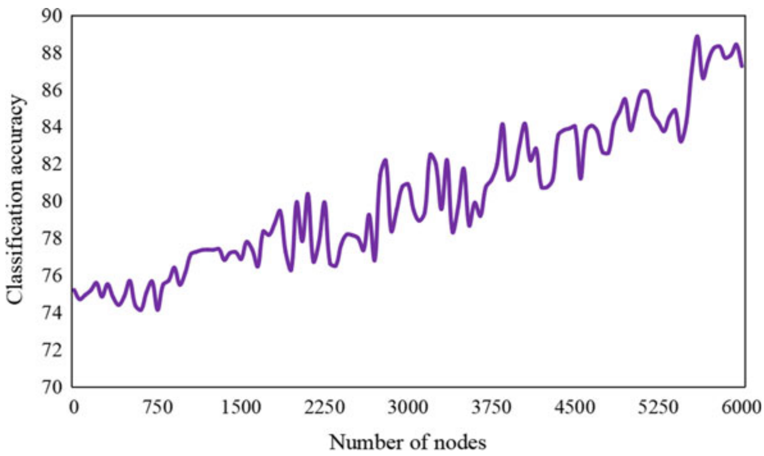

Fig. 7.2 Improving the accuracy of CNN feature extraction

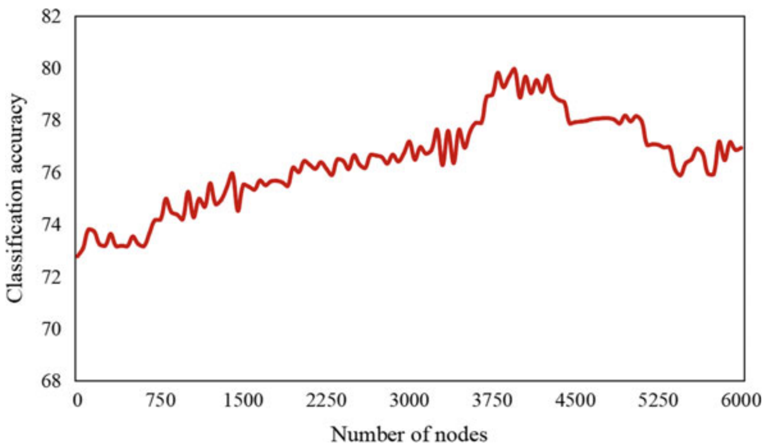

Fig. 7.3 Accuracy of traditional CNN feature extraction

transmittance parameters outside the atmosphere, and the calculation results of 3D scene and direct sunlight visibility are read in.

It does not require that the radiation of the simulation result is exactly the same as that of the actual scene, but it pursues the equivalent effect of the two under the observation of the infrared imaging system. Therefore, to simulate the infrared imaging by computer, we must start from the aspects of simulating the geometric characteristics of the scene, the infrared radiation characteristics and the effects of the atmosphere and the imaging system on the infrared radiation of the scene. Compare the recall and MAE of infrared image feature extraction model based on improved CNN with traditional CNN, and the results are shown in Figs. 7.4 and 7.5.

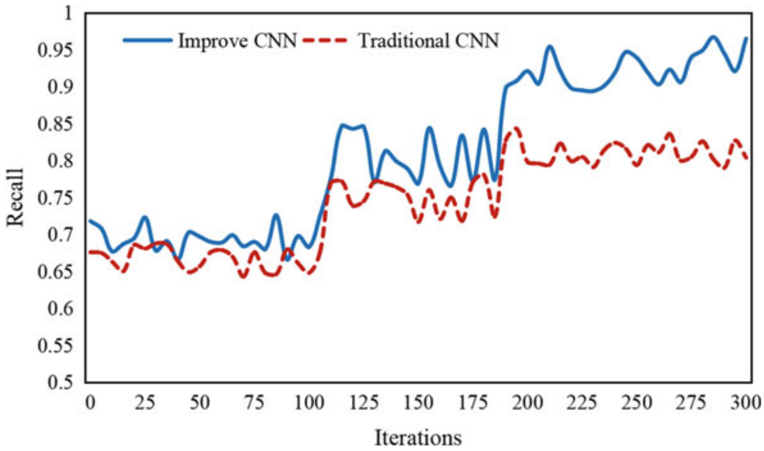

Fig. 7.4 Comparison of recall rates

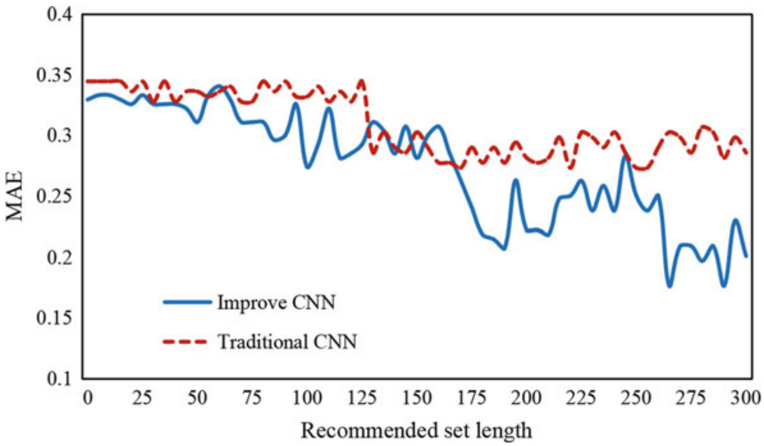

Fig. 7.5 Comparison of MAE

There are many related images in the image, and the images with high similarity rank high in the retrieval output, which can realize good retrieval expectation. As can be seen from Figs. 7.4 and 7.5, after many iterations, the accuracy of the improved CNN is better than that of the traditional CNN, reaching more than 95%, and the error is also significantly reduced. Through the improvement of this article, the convergence speed of the improved CNN parameters is faster, and finally, the modeling accuracy is higher. This method obtains ideal infrared image feature recognition results, and the recognition accuracy is higher than other feature extraction methods. Although the radiation of the generated infrared image is not exactly the same as that of the actual scene, they have equivalent effects under the observation of the infrared imaging system, which realizes the omni-directional, multi-angle and scientific management and control of tasks, simulation design, implementation coordination, efficiency evaluation and intelligent decision-making in real-time infrared simulation design.

7.4 Conclusion

Infrared imaging simulation technology has been widely used in military fields such as night navigation, optical remote sensing, precision guidance and target detection. Because the field test can get the real evaluation results, it is an accurate method to complete the dynamic test, but because of its shortcomings such as high cost, long cycle, high risk and large resource consumption, it cannot meet the technical research and progress requirements in the process of weapon development, thus restricting the effectiveness of its evaluation. Driven by AI technology, this article proposes an infrared 3D scene modeling algorithm based on improved CNN. After many iterations, the accuracy of the improved CNN is better than that of the traditional CNN, reaching more than 95%, and the error is also significantly reduced. Through the improvement of this article, the convergence speed of the improved CNN parameters is faster, and finally the modeling accuracy is higher. Although the radiation of the generated infrared image is not exactly the same as that of the actual scene, they have equivalent effects under the observation of the infrared imaging system, which realizes the omni-directional, multi-angle and scientific management and control of the real-time infrared simulation design. The infrared simulation system in this article simulates the scene on the ground, and the function of the system can be further improved and expanded in the future, so that it can support the scene simulation of the ocean and the sky and further strengthen the universality of the infrared simulation system.

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