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末敏弹室内半实物仿真系统设计

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摘　要：设计了末敏弹红外敏感器室内半实物仿真系统，研究了末敏弹在攻击目标过程中的姿态控制以及对目标的识别率. 系统采用半实物仿真技术，利用 Multi-Gen Creator 软件生成战场环境中所需要的场景和目标的三维可见光模型，并附上相应红外纹理. 通过虚拟视场样机模拟生成红外敏感器扫描视场所产生的场景的红外数字信号. 将末敏弹的探测系统——红外敏感器作为实体引入到仿真系统中参与试验，并和其它物理模型、数学模型构成闭合回路，完成了末敏弹的实时仿真功能. 仿真结果表明，红外敏感器能够对目标进行完全识别，并具有误检率和漏检率低的优点.

关键词：末敏弹；半实物仿真；红外敏感器；光学系统；三维建模；实时

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Design on Indoor Hardware-in-loop Simulation System for Terminal Sensitivity Projectile

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Abstract: The hardware-in loop simulation technology was employed to design the indoor hardware-in loop simulation system for infrared sensor of terminal sensitivity projectile. This system employs the Multi-Gen Creator to build the scene model and the attacked target three-dimensional geometrical model as well as employs the Multi-Gen Vega to produce the digital scene of detection field for terminal sensing projectile. Meanwhile, the detection system of terminal sensitivity projectile-infrared sensor was served as the substance and introduced into the simulation system to participate in the test and consist of the closed loop with other software systems and optical system complete the real-time simulation function of terminal sensitivity projectile. The simulation result indicates that the infrared sensor can completely identify the target and is provided with such advantages as low false detection ratio and low omission ratio.

Key words: Terminal sensing projectile; Hardware-in-loop simulation; Infrared sensor; Optical system; Three-dimensional modeling; Real time

OCIS Codes: 040.3060; 040.0040; 040.5160

0 Introduction

The terminal sensitivity projectile is a kind of projectile that the target orientation can be detected to enable that the warhead flies towards the target direction. It is mainly used for top armor of self-attack

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armored vehicles and features long operational distance, high shot probability, good damaged effect and high benefit-cost ratio, etc. Developed military countries have attached great importance to it and are competing to carry out related research. During the Eighth and Ninth Five-year plan[1-2], some pre-research work has been carried out; Part of technology, including target detection technology, explosively formed projectile, stable scanning technology, etc. achieved a major breakthrough.

The detection system is a crucial component part and the efficiency directly decides the efficiency of the entire terminal sensitivity projectile. In the hardware-in loop simulation, the detection system of terminal sensitivity projectile infrared sensor is served as the substance to participate in the test and consist of the closed loop with other physical models and mathematical models[3]. Such simulation test can get the response signal from the detection system conveniently and accurately and the test result is more complete, target and true than the one of simple mathematical simulation[4]. This paper is to research detection performance of terminal sensitivity projectile by employing hardware-in-loop simulation technology, including spiral scanning algorithm of terminal sensitivity projectile landing, design of dual-band optical path synthesis, high-speed data acquisition and 3D Demo of terminal sensitivity projectile attack target, etc. It also provides a feasible solution for future weapon development.

1 Integral framework of system

The entire system is composed of simulation software system, hardware control system and the light source system. The simulation software includes the virtual battlefield environment modeling, virtual view prototype module and the evaluation software; the hardware system includes the light source control, signal acquisition and the detection system (infrared sensor of Terminal Sensitivity Projectile); the light source system includes the far-infrared and near-infrared laser and the light path synthesis.

The entire system not only provides an intuitive visualization platform for terminal sensitivity projectile searching, detecting and attaching the target, but also adopts hardware-in-loop simulation technology. The result is more accurate than the one of simple mathematical simulation adopted in the Ref. [4]. The system block diagram is shown in Fig. 1.

This system serves the high-speed computer as the computing platform and the control center as well as serves infrared scene the target and background

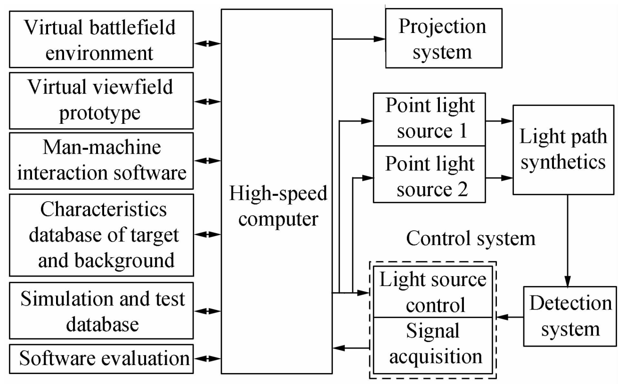


Fig. 1 Structure of infrared sensor of terminal sensitivity projectile

database as the base, and the Multi-Gen Creator modeling tool is employed to build the background and target three-dimensional geometrical model for the ground[4-5]. Based on the developed three-dimensional infrared scene simulation software, the dual-waveband infrared digital scene required for the simulation test is generated for the sensor. The light source controller shall be converted as the energy control signal for infrared laser from the digital signal of instantaneous infrared field radiation for the virtual field prototype obtained from the simulation software. Two ways of light source is controlled by respective modulating signal, the modulated two-waveband infrared radiation integrates the two-waveband infrared collimation laser beam into one-way composite infrared radiation to irradiate on the radiation reception surface of sensor by the optical path synthesizer. The sensor presents the response for the infrared radiation outputted from the light source system in the process of simulation (searching, discovering and assaulting) and outputs the response electric signal, while the data collector acquires the response signal form the sensor in real time and feed it back to the virtual scene simulation system via the date acquisition interface, then the virtual scene simulation system stores the acquired signal into the simulation test simulation to employ and process these data by the evaluation software as well as evaluate the sensor[5-6].

2 Simulation software system

The software system is composed of three-dimensional object and background model creation, target attitude control, terminal sensitivity projectile attitude control, dual-band infrared scene generation, dual-band infrared scene/target digital sequence generation and man-machine interface. The block diagram of system software is shown in Fig. 2.

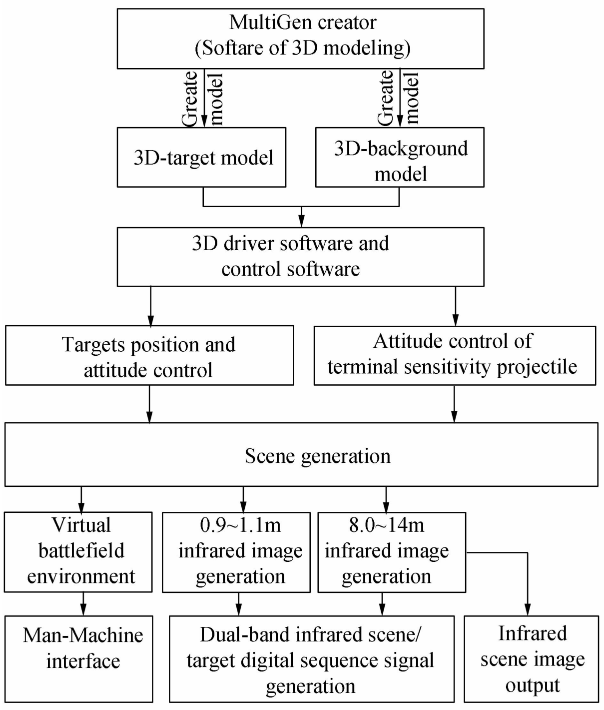


Fig. 2 System software block diagram

2.1 Three-dimensional modeling of ground scene and target

Types of ground background include sand, snow, grass, bare soil, roads, water, simple structures and their integrated battlefield environment.

The specific implementation method is as follows: firstly, determine the size of ground scene according to the range of terminal sensitivity projectile; secondly, generate grayscale image with default shape and contours, and convert grayscale image into standard Digital Elevation Model (DEM) with a conversion tool; then use Multi-Gen Creator to achieve the set number of triangles and embody realistic surface three-dimensional envelope line as far as possible; finally, add soil, vegetation, water and other backgrounds onto the undulant surface to synthesize three-dimensional ground scenes.

Target types include: tanks, armored vehicles, self-propelled guns, missile launchers and command posts and other important military targets on the ground. The number of targets in the scene can be set to be any integer between 0 and 10. The maximum movement velocity of vehicle is about 60～80 km/h.

The specific method: firstly, complete three-dimensional geometric modeling of the target and ground facilities with different precisions by employing Multi-Gen Creator according to LOD (Layer of Detail) theory in computer graphics; then select different materials for different units of the target and ground facilities, different materials have different emissivity. The model of ground scene and target three-dimensional modeling are shown Fig. 3.

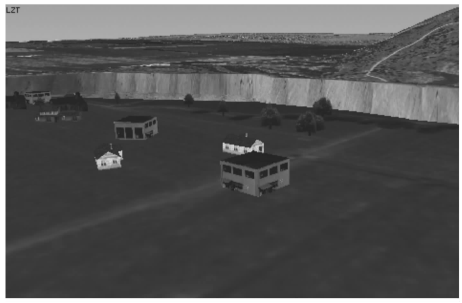


Fig. 3 Ground scene and target three-dimensional modeling

2.2 Virtual battlefield environment

The focus of virtual battlefield environment is the whole scene, producing visible light scene. The completed functions include multi-objective control and management, attitude control of terminal sensitivity projectile and effects processing of projectile shooting, etc. In the simulation process, roaming of scene images can be controlled via the keyboard and mouse to synchronically display the whole process of terminal sensitivity projectile searching and tracking the target in real time from multiple perspectives.

1) Multi-objective control and management. Battlefield environment should contain many dynamic targets, and the targets can automatically move on the track. Employ a separate thread to control the movement of the target and manage all threads with one thread management class.

2) Establish stable scanning model equation of terminal sensitivity projectile. It will play a decisive role in the accuracy of terminal sensitivity projectile capturing and identifying the target whether it can achieve stable scanning. The falling process of terminal sensitivity projectile includes the movement of both the parachute and the projectile. The motion equations of the parachute and the projectile are established respectively as follows[7].

Differential equations of parachute mass center movement are

$$\begin{cases} \dot{V}_{1x_0} = \dfrac{1}{m_1}(R_{1x_0} + N_{1x_0}) \\ \dot{V}_{1y_0} = \dfrac{1}{m_1}(R_{1y_0} + N_{1y_0}) \\ \dot{V}_{1z_0} = \dfrac{1}{m_1}(R_{1z_0} + N_{1z_0} - m_1 g) \end{cases} \quad (1)$$

Therein, m_1 is the mass of parachute; R is the air resistance and lift force on the parachute; N is constraint force. $\dot{V}$ is the velocity vector of the parachute.

Differential equations of projectile on-center movement are

$$\begin{cases}\omega_{1x_1}=\dot{\rho}_1\sin\theta_1\sin\varphi_1+\dot{\theta}_1\cos\varphi_1\\ \omega_{1y_1}=\dot{\rho}_1\sin\theta_1\sin\varphi_1+\dot{\theta}_1\sin\varphi_1\\ \omega_{1z_1}=\dot{\rho}_1\cos\theta_1+\varphi_1\end{cases}\quad(2)$$

Differential equation of projectile mass center movement are

$$\begin{cases}\dot{V}_{2x_0}=\frac{1}{m_2}(-N_{1x_0})\\ \dot{V}_{2y_0}=\frac{1}{m_2}(-N_{1y_0})\\ \dot{V}_{2z_0}=\frac{1}{m_2}(-N_{1z_0}-m_2g)\end{cases}\quad(3)$$

Therein, m_2 is projectile mass N is constraint force; $\dot{V}$ is the velocity vector of projectile mass.

Differential equations of projectile on-center movement are

$$\begin{cases}\omega_{2x_2}=\dot{\rho}_2\sin\theta_2\sin\varphi_2+\dot{\theta}_2\cos\varphi_2\\ \omega_{2y_2}=\dot{\rho}_2\sin\theta_2\sin\varphi_2+\dot{\theta}_2\sin\varphi_2\\ \omega_{2z_2}=\dot{\rho}_2\cos\theta_2+\varphi_2\end{cases}\quad(4)$$

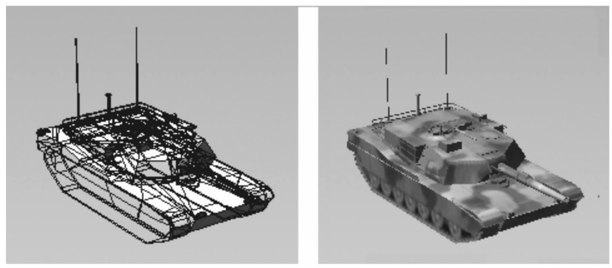
3) Effect processing of projectile shooting. The special effect of smoke in the terminal sensitivity projectile attacking process can be produced by mapping multiple continuous flame images onto a plane through a transparent texture, setting the background to be transparent and continuously changing the textures[8].

2.3 Acquisition of infrared radiation data of target and background

The generation of infrared image is related to the object radiation energy received by the detector, and the object radiation is a quantity related to many factors, such as the surface radiation, sky background radiation, solar radiation and atmospheric radiation. Such data can be acquired through infrared radiation modeling of the target and ground objects as well as analog calculation.

1) Target and background surface radiation temperature assignment: in view of three-dimensional undulant topography spliced with triangles as basic primitives, designate a specific radiation temperature value for every triangle basic unit to determine its gray value. For all the triangular units in the terrain, group the triangles by type and designate its radiation temperature value by group[7].

2) Surface texture mapping of target and background: The radiation temperature values assigned to the target and background surface only indicate the average radiation on surface and cannot indicate the detailed distribution on the surface. As the details of the scene in the nature is quite complex, surface texture is such manifestation. That problem can be solved by employing the texture mapping technology. Main steps of infrared texture mapping: process visible light texture image to generate data that reflects the materials; employ visible light images to locate and determine the texture coordinates, i.e. when using the three-dimensional modeling tool, use specific pictures for mapping; after mapping, complete the mappings from material to graph by assign an ID to the material[9]. Acquire infrared texture data of materials according to the material temperature and property data; map infrared texture data on the basic primitives to generate infrared three-dimensional scene with undulant surface grey values. The model result of material and texture mapping are as shown in Fig. 4.



(a) Modeling of 3D grid target (b) Target of texture mapping

Fig. 4 Target modeling and texture mapping

2.4 Simulation system running interface

The simulation software mainly completes the generation for corresponding battlefield environment and the generation function as well as the display function based on the instantaneous scene corresponding to the detection view field of infrared sensor for simulation background model. Fig. 5 shows the interface of hardware-in-loop simulation, the simulation demonstration shows that the terminal sensitivity projectile is performing the ground scanning to search the target.

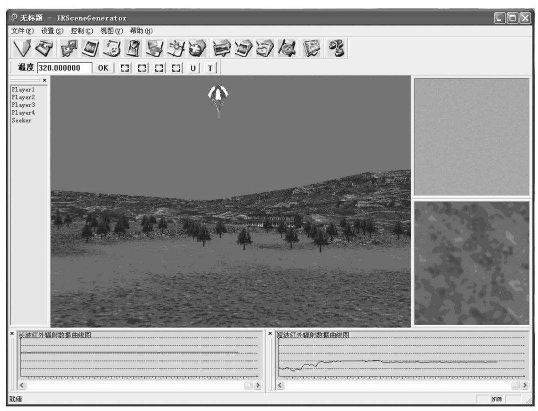


Fig. 5 Virtual battlefield environment

The main picture of system operation interface shows that the simulated terminal sensitivity projectile is scanning the ground surface in the declining process; the two small images on the right are instantaneous fields of view obtained by near-infrared and far-infrared scanning; the two small images below are sequences of numbers of far-infrared band and near-infrared band generated by terminal sensitivity projectile in scanning the scene[10]. The simulation software flow diagram is shown in Fig. 6.

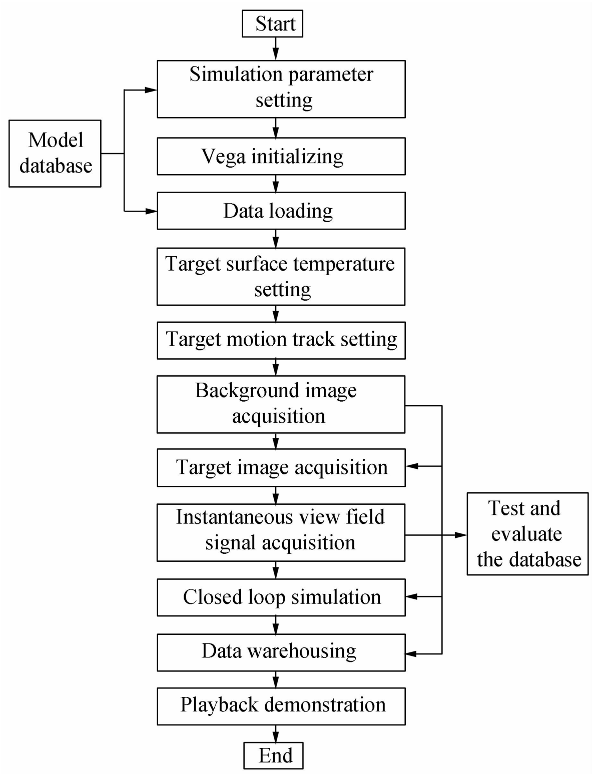


Fig. 6 System simulation flow diagram

Program Output:

1) Synchronously display the generated instantaneous view scene as well as the serial signal curve for one-dimensional radiation on the user interface.

2) Output the serial signal for one-dimensional radiation onto the USB data transmission interface.

3 Hardware system

The system serves the two-tone infrared sensor as the application background and employs the virtual reality technology to build the virtual view-field prototype of sensor. Under the typical fighting environment, the verification and evaluation on search and detection performance for armored target on the ground are performed to study the discipline of the overall parameters of sensor to target searching and detection as well as explore the design criteria of sensor[11-12].

The hardware system is composed of such six parts as the workstation of prototype, light source controller, long and short wave laser, light path synthesizer, detector and the data collector. The integral block diagram of hardware system is as shown in Fig. 7.

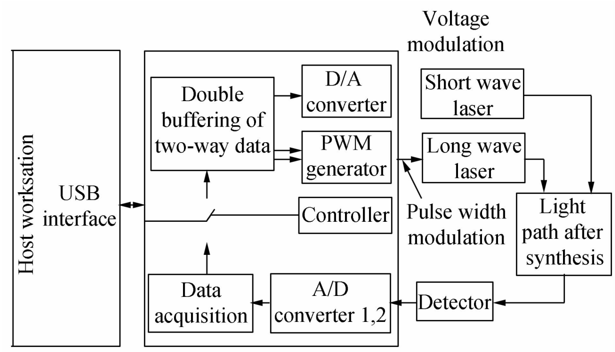


Fig. 7 Block diagram of hardware-in-loop simulation system for two-tone infrared sensor

The computer with host workstation level is served as the computing platform and the control center; the three-dimensional modeling tools are employed to establish the three-dimensional geometrical model of ground background and target; the Vega three-dimensional drive software is employed to generate the double waveband infrared digital scene required by the simulation test of infrared sensor to be output onto the light source controller via the USB interface of host6. The light source controller converts the digital scene signal corresponding to the short waveband to be the analog signal to control the infrared irradiation modulator and modulate the short waveband laser via D/A converter; the digital scene signal corresponding to the long waveband is converted to be PWM signal to modulate the long waveband laser via the PWM inside the light source controller. After the two waveband infrared irradiation modulated specially enters into the light path synthesizer after being attenuated by the filter sheet and the slit as well as being expanded and collimated, the light path synthesizer synthesizes the two waveband infrared collimated beam into one path according to the requirement to supply the receiving by the infrared sensor (detector). Finally, the A/D converter in the collector collects the response signal of infrared sensor and the digital quantity after being acquired is transmitted to the host workstation via the USB2. 0 interface to complete the verification and the evaluation on performance of detector by the evaluation software[13-14].

4 Synthetic system of light source

The light path synthesizer is composed of the reflecting mirror, interference filter and the optical slit, the function is to synthesize the near-infrared irradiation and the far-infrared irradiation to be one path to receive the two-tone infrared detector simultaneously[15-16]. The schematic diagram is as shown in Fig. 8.

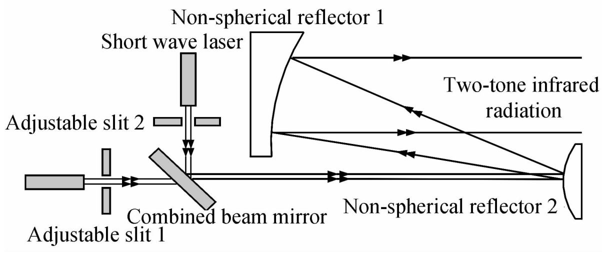


Fig. 8 Schematic diagram on synthesis of path for lignt source system

5 Simulation Result

Fig. 9 shows the simulation waveform when the entire simulation system is debugged jointly, therein, waveform 1 is of the target scanned by the prototype on the virtual view field, with 5 targets totally; waveform 2 is of the identified target after judgment by certain algorithm, with 100% for recognition ratio of target. It is indicated that the data transmission process is correct[17]. Meanwhile, seen from the waveforms detected by the oscilloscope, the simulation time scale is consistent with the actual one, which has met the real time requirement of the simulation system[18].

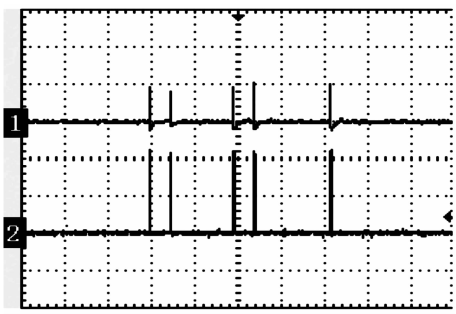


Fig. 9 Identified target simulation waveform

6 Conclusion

In hardware-in-loop simulation, a simulation technology with a high degree of confidence, the core component of terminal sensitivity projectile-infrared sensor is introduced to the circuit of simulation system. Meanwhile, the data of virtual prototype scanning the field of view and the data of infrared sensor are transmitted to the computer via high-speed USB2.0, and double-buffering of the data is achieved in FPGA to ensure the real-time data transmission. Therefore, compared with the computer software simulation method mentioned in Ref.[4], the simulation result is more closer to the actual situation and also more accurate. Restricted by the hardware of the system and considering the real time of system, the stable scanning of terminal sensitivity projectile in system design is simplified. In later work, we will focus on the in-depth research of stable scanning technology of terminal sensitivity projectile under different circumstances.

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