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Study on Stable Scanning of Terminal Sensitivity Projectile and Hardware-in-the-Loop Simulation System

Yuan Wei[1, 2], Zhang Jianqi[1], Feng Yang[2]

[1]School of Physics and Optoelectronic Engineering of Xidian University, Xi'an, P. R. China
[2]Physics and Electrical Engineering College of Weinan Normal University, Weinan, P. R. China

Email address:
wnyuanwei@163.com (Wei Yuan)

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Abstract: In order to study the attitude control and target detectivity of terminal sensitivity projectile during the process of attacking the target, theoretical modeling is firstly conducted for the steady scanning process of terminal sensitivity projectile; on this basis, the core part of terminal sensitivity projectile -- infrared detector is introduced as hardware to hardware-in-the-loop simulation loop with hardware-in-the-loop simulation technology and virtual reality technology, and an analysis is made from the aspects of attacking accuracy, false detection rate and miss rate of terminal sensitivity projectile to verify the performance of such detector and also provide reference for new weapon development in the future.

Keywords: Terminal Sensitivity Projectile, Steady Scanning, Hardware-in-the-Loop Simulation

1. Introduction and Definitions

Terminal sensitivity projectile is a kind of special cluster bomb projected by an aircraft or artillery. It has no guidance system, so it cannot automatically track the target as missiles guided by visible light, infrared light or millimeter wave. But, as anti-armor ammunition, it has the advantages of long attack distance, higher hit rate than conventional artillery shells and lower cost than missile. Therefore, it has broad application prospects in the fight against armored targets. [1]

In this paper, through detailed analysis and study of the scanning process of artillery-projected parachute-bomb terminal sensitivity projectile as well as simplified modeling, mathematical modeling is conducted for the stable scanning process of this projectile to study the formation mechanism of terminal sensitivity projectile scanning track, so as to provide a theoretical basis for later hardware-in-the-loop simulation.

2. Terminal Sensitivity Projectile Scanning Track Formation Mechanism

For the reason of installation, there is an included angle between the projectile axis and the vertical axis, called scanning angle θ_{scan}. After a terminal sensitivity projectile is projected by an artillery or aircraft and enters stable scanning, scanning in spiral falling will be conducted. The mass center of terminal sensitivity projectile body falls approximately perpendicularly at a constant speed, and the projectile axis rotates on the vertical axis. The speed of this rotation is called angular scanning rate of terminal sensitivity projectile ω_{scan}. In addition, terminal sensitivity projectile also rotates on its own axis and the angular velocity of this rotation is called spin velocity ω_{self} .[2]

Suppose the coordinates of the initial location of the terminal sensitivity projectile mass center are $C(x_c, y_c, z_c)$, the distance from the projectile mass center to the ground along the projectile axis is $l = \left|\frac{z_c}{\cos\theta_{scan}}\right|$ and the scanning track at the time is:

$$\begin{cases} x = x_c + l\cos(t\omega_{scan}) \\ y = y_c + l\sin(t\omega_{scan}) \end{cases}$$

During stable scanning, ω_{scan} and θ_{scan} are constant; another form of expression of the scanning track is as follows:

$$\left(x-x_c\right)^2+\left(y-y_c\right)^2=z_c^2tg^2\theta$$

It can be known from Equation (1) that, in the stable scanning of terminal sensitivity projectile, the scanning track is a group of concentric circles with center at (xc, yc) and radius equal to |zctgθ|. With the falling of the projectile body, z_c is decreases and the radius also becomes smaller and smaller. Therefore, the scanning track is a group of internal spiral lines.[3]

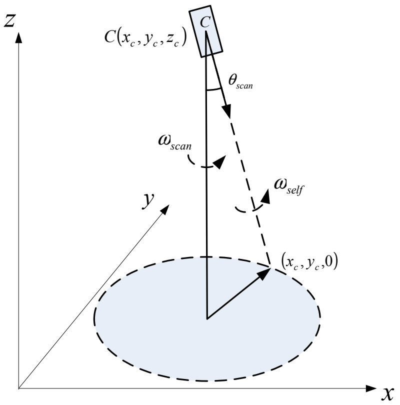

Fig. 1. *Scanning track formation mechanism.*

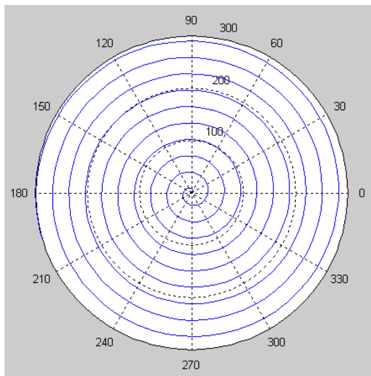

Fig. 2. *Spiral line of ground scanning during falling of terminal sensitivity projectile.*

3. Modeling for Gain Characteristics of Highlight Source Interference Low-Light Imaging System

For a terminal sensitivity projectile, the detection system is a very important part and its performance directly determines the effectiveness of the entire projectile. In hardware-in-the-loop simulation, the detection system of terminal sensitivity projectile is put in the test as an entity to form a closed loop together with other physical models and mathematical models. Through such simulation tests, response signals of detection system can be easily and accurately obtained and the test results are more comprehensive, objective and real than that of purely mathematical simulation. Fig. 3 is the logic diagram of hardware-in-the-loop simulation system of infrared detector. It describes the logical relationship between different functional modules involved in this system.[4]

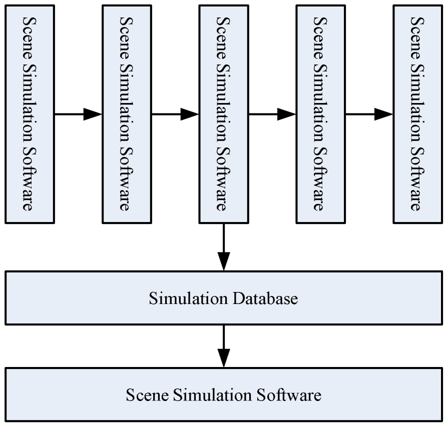

Fig. 3. *Logic diagram of hardware-in-the-loop simulation system of infrared detector.*

3.1. Integral Framework of System

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 database as the base, and the MultiGen Creator modeling tool is employed to build the background and target three-dimensional geometrical model for the ground2. 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 two–waveband infrared radiation that has been modulated 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, and 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]The block diagram of the hardware-in-the-loop simulation system is as shown in Fig.4. The entire system is composed of such parts as the 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 and 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. [7][8]

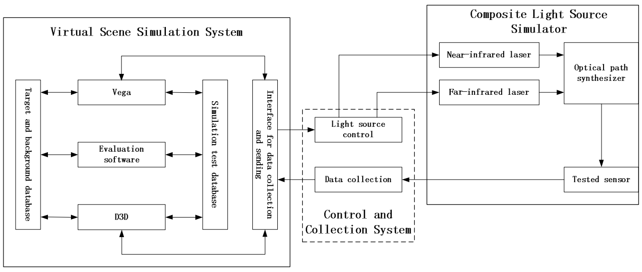

Fig. 4. *Hardware- in-the-Loop Simulation System Structure of Infrared Sensor of Terminal Sensitivity Projectile.*

3.2. Virtual Scene Simulation System

In this system, three-dimensional model of the simulation object is fabricated with virtual scene simulation technology to achieve very realistic simulation results. It is divided into simulation environment fabrication and simulation drive. Simulation environment fabrication mainly includes model design, scene construction, texture design and fabrication and special effect design, etc. It requires the construction of realistic 3D models and the fabrication of realistic texture and special effects. Simulation drive mainly includes scenario drive, model mobilization, distribution interaction and large terrain treatment, etc. It requires high-speed and realistically reproduction of simulation environment and real-time response to interactive operation, etc. It is an interactive simulation environment making the user feel as if he were there, thus achieving direct and natural interaction between user and the environment. Fig.5 shows a simulated battlefield environment in the virtual scene simulation environment.

Fig. 5. *Vega-driven weapon carrier roaming at the scene.*

Fig. 6 shows the interface of hardware-in-the-loop simulation system software. The simulation demonstrates that a terminal sensitivity projectile is scanning the ground in search of target. The parachute-projectile model is a terminal sensitivity projectile; the two curves below the interface are simulated long-wavelength and short-wavelength infrared radiation data detected by the terminal sensitivity projectile; the two square zones on the right are the instantaneous fields of view of the two wave bands detected by the projectile in scanning. Player 1 - player 4 in the left column are simulated targets placed on the ground, and all are models of tanks, armored vehicles and self-propelled artillery, etc. [9]

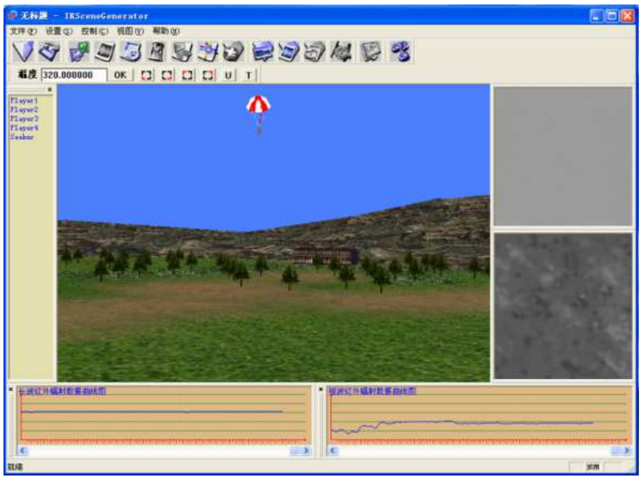

Fig. 6. *Screen shot for System Software Interface.*

3.3. Design of Composite Light Source Simulation System

According to the simulation needs, two infrared lasers with different service bands are used as the fundamental infrared light source. In this bi-color infrared hardware-in-the-loop simulation system, the optical distance from the light source to detector is very short and laser beam have very high degree of parallelization. Therefore, we do not use collimator to parallel and collimate output beam. We only need to design a set of combiner to combine two laser beams into one and expand it with an expander to a proper size for entrance pupil of detector. The logic structure of composite light source simulation system is shown in Fig. 7.[10]

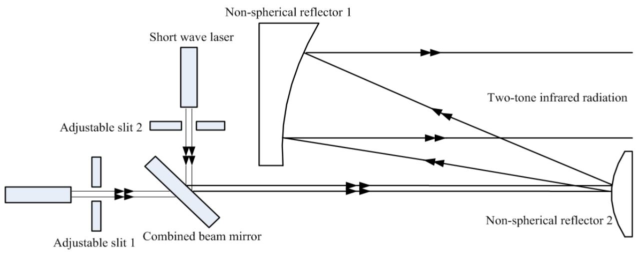

Fig. 7. *Schematic Diagram on Synthesis of Path for Lint Source System.*

3.4. System Simulation Test

After the composite light source simulation system test, the two subsystems of control and collection system and virtual scene simulation system were also tested. Under the condition that all subsystems work normally, the overall test of the entire system was completed. The test results are shown in the figure below:

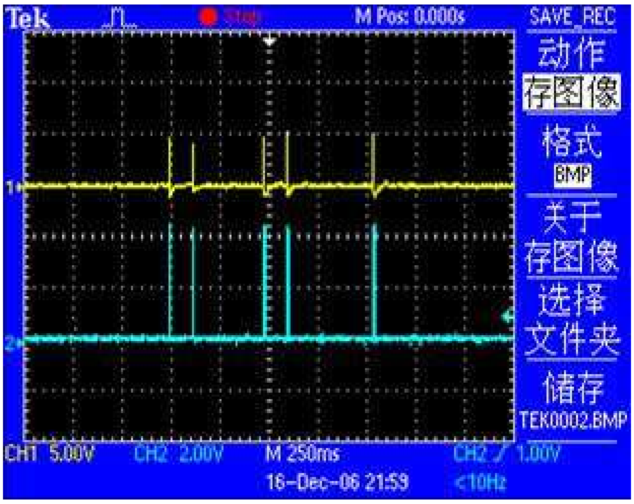

Fig. 8. *Identified Target Simulation Waveform.*

Fig. 8 shows the simulated waveforms of the whole simulation system in joint debugging. Waveform 1 (upper) indicates the target scanned by the virtual scene model machine and a total of 5 targets are discovered; waveform 2 (lower) is the target identified by the detector by judging with certain algorithm, and the target identification rate is 100%. It indicates that the data transmission process is correct and that the system can fully identify targets, which is consistent with the theoretical analysis result and meets the simulation requirements.

4. Conclusion

In this paper, hardware-in-the-loop simulation system is designed and takes infrared detector of terminal sensitivity projectile as simulation object to realistically realize the stable ground scanning process of terminal sensitivity projectile on the basis of theoretical modeling of stable scanning of the projectile. In addition, virtual reality technology is used to generate a scene close to the real environment as much as possible, and proper light source controller and composite light source simulation system are designed to provide the detector with infrared radiation energy approximate to that detected in combat environment; then its response signals are collected and simulation and evaluation software is used to analyze these signals, achieving simulation of the process of terminal sensitivity projectile attacking targets and providing reference for pre-development of weapons.

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