Research on Key Technologies of Photoelectric Guided Weapons and Their Development Trends

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Abstract

With the rapid development of signal processing and semiconductor technology, photoelectric guidance technology plays an increasingly important role in precision strike weapons because of its strong anti-interference ability, long range of action and high hit accuracy. This paper first analyzes the transmission characteristics of photoelectricity in the atmosphere; introduces the basic principles and key technologies of infrared and laser two main guidance methods from optical system, detector original and information processing system; The development trend is forecasted.

Keywords

Photoelectric guidance; infrared; laser; atmospheric transmission.

1. Introduction

Since the Gulf War, precision strike weapons have played an increasingly important role in modern battlefields. Among them, the photoelectric guided weapon utilizes the photoelectric effect of the semiconductor device to detect the infrared radiation, laser and millimeter wave emitted or reflected by the target, and identifies and tracks the target and its position according to the information in the photoelectric radiation, and finally guides the warhead to hit the target. Compared with the traditional guidance method, the photoelectric guidance method can be used around the clock, and has the advantages of strong atmospheric transmission capability, long working distance, strong anti-interference ability and high cost-effectiveness. It has become the main development direction of future war.

2. Atmospheric transmission

The influence of the atmosphere on electromagnetic waves is mainly divided into scattering and absorption. When light passes through the atmosphere, atoms or molecules in the atmosphere absorb photon energy and are excited and released in the form of heat, radiant energy or chemical energy. Light of different wavelengths has different ability to be absorbed. In addition, when photons react with atmospheric particles, they will scatter, and the direction and intensity of light will change. Due to factors such as scattering and absorption, the transmittance of a part of the band of the light source in the atmosphere is small or impossible to pass. A band with a high transmittance through which electromagnetic waves are less reflected, absorbed, and scattered through the atmosphere is called an atmospheric window.

(1)0.3～1.155μm, Ultraviolet, visible, near-infrared.

(2)1.4～1.9μm, Near-infrared window, transmittance 60% to 95%.

(3)2.0～2.5μm, Near infrared window, transmittance 80%.

(4)3.5～5.0μm, Mid-infrared window, transmittance 60% to 70%.

(5)8.0～14.0μm, Thermal infrared window with a transmission rate of 80%. Mainly from the heat radiation energy of the object. Suitable for nighttime imaging and also for long-wave infrared.

In addition, bad weather such as fog, haze, rain, snow, clouds and dust will affect the transmission of optoelectronics in the atmosphere. In the design and analysis of photoelectric detection systems and test identification, the effects of atmospheric and photoelectric information and energy need to be considered.

3. Infrared guidance

3.1 Infrared guidance principle

Every object with heat radiates energy outward, and its radiant energy is related to the temperature of the object and the wavelength of the radiation. Planck derived a radiation formula that conforms to quantum theory based on the original short-wave and long-wave blackbody radiation formulas.

$$M(T)=\frac{2\pi hc^2}{\lambda^5(e^{hc/\lambda KT}-1)} \tag{2.1}$$

It can be known from equation (2.1) that the blackbody with different temperatures radiates different energy, and the radiation emittance increases with the increase of temperature; while the actual object is called gray body, the emission capability is not blackbody. In actual warfare, many military targets, such as airplanes, rockets, tanks, etc., generate a large amount of heat during their operation, and the infrared radiation radiated outward is much higher than the environmental background. Infrared guidance is the use of this difference in infrared radiation, through the infrared detector to capture and track the energy of the target's own radiation, to achieve the guidance of the search. Since the infrared guidance method utilizes the target's own outward infrared radiation and does not require external illumination, it is a passive homing guidance method, and has the advantages of all-weather combat, good concealment, and strong anti-interference ability compared with other photoelectric guidance methods. Infrared guidance is divided into infrared point source guidance and infrared imaging guidance. Infrared point source guidance means that the system opening angle is smaller than the instantaneous field of view and the target signal source details cannot be resolved. The target radiation information is used to obtain the target position, and the ammunition is directed to hit the target. Infrared point source guidance systems are usually composed of optical systems, modulators, infrared detectors, refrigerators, servos, and electronic circuits.

The infrared point source guided weapon has the characteristics of simple structure, low cost and reliable operation. However, since it can only output the target point angle information, it has no ability to distinguish the target, and is susceptible to false target interference and complex background interference.

Infrared imaging guidance technology uses detectors to convert target and background radiation into different electrical signals, using digital signal processing to analyze and track targets. The infrared imaging guidance system generally consists of an infrared camera, an image processing circuit, an image recognition circuit, a tracking processor, and a camera tracking system, as shown in Figure 1.

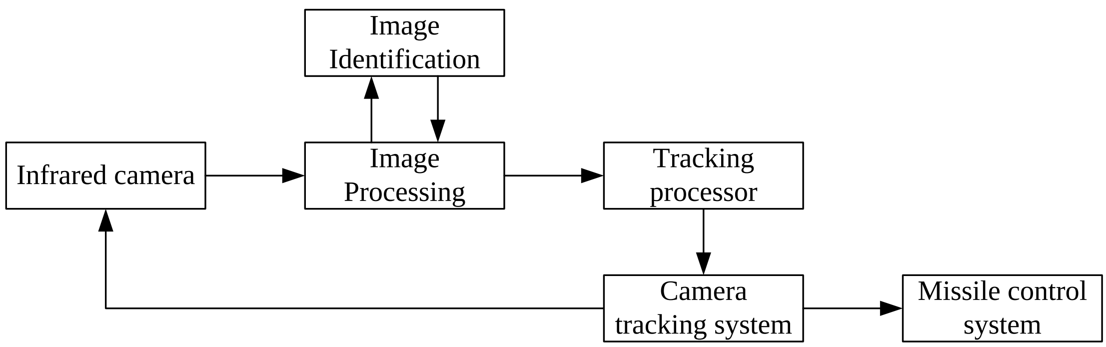

Figure 1 Infrared imaging guidance system

Infrared imaging guidance technology relies on different target and background radiance to detect, uses thermal image to identify targets, has strong anti-interference ability, high spatial resolution, long detection distance and strong anti-interference ability, and has gradually replaced infrared point source guidance. It has become the main development direction of current and future infrared guided weapons.

3.2 Key technology

3.2.1 Infrared optical system

The infrared optical system includes a fairing, an infrared optical lens system and the like.

The fairing protects the seeker system from the harsh airflow environment and is transparent to the infrared radiation of a particular band. The air resistance and infrared radiation generated by the missile during flight are the important factors affecting the shape and material of the fairing. At present, new fairings such as multi-faceted cones and multi-lenses can meet the needs of both.

Infrared optical lenses are part of the optical system and an important part of the infrared seeker. Due to the high sensitivity and high performance requirements of the infrared seeker, the optical system must have the following features:

(1) 100% luminescent efficiency. The cold light is set to limit the unnecessary heat source interference outside the field of view of the detector. The infrared optical system designed for the cooling type detector must be considered to match the 冷 and cold light, to ensure 100% cold light matching efficiency.

(2) High image quality. In order to enable the missile to find and stabilize the tracking target from a long distance, more target information needs to be obtained, and the resolution requirement for details is also higher and higher, which requires the optical system to approach the diffraction limit.

(3) High transmittance. Transmittance is an important indicator of the infrared seeker optical system, which directly affects the range of the seeker and the signal-to-noise ratio of the image. Therefore, the transmission rate of the infrared optical system is required to be as high as possible, and the technical means for increasing the transmittance of the optical system are both an anti-reflection coating and a reduction in the number of lenses. At present, coating technology has become more mature, so the use of binary optics, aspherical mirrors and other measures to reduce the number of lenses.

(4) No heating infrared seeker. The temperature range of the working environment is relatively large. The curvature, thickness and spacing of the optical components change when the temperature changes. The refractive index of the element matrix material and the refractive index of the surrounding medium also change. The refractive index of most infrared lens materials varies with temperature. The changes are significant, and these changes cause the image plane of the infrared optical lens to change to cause a change in image quality. Therefore, the infrared imaging system must be designed to be non-thermalized to compensate for image surface drift caused by temperature changes.

In response to the above requirements, the current infrared optical system generally adopts high-order aspherical design technology, which can reduce the number of lenses and increase the transmittance to meet the image quality requirements. At present, typical non-thermal design techniques can be divided into three categories: mechanical passive heatless technology, mechanical (electronic) active heatless design and optical passive heatless design technology. Among them, optical passive technology has the highest comprehensive efficiency and light weight. It does not require power supply and high reliability, especially suitable for infrared imaging guidance systems.

3.2.2 Infrared detectors

The infrared detector is an inductive element that converts infrared radiation into an electrical signal. Its range of action has experienced a process of 1 to 3 μm near-infrared, 3 to 5 μm medium-wave infrared, and 8 to 14 μm long-wave infrared. The atmospheric transmittance of infrared radiation has a high transmittance in three bands. In addition, the working frequency of infrared guided weapons is mainly considered according to various factors such as target radiation, detector development level and battlefield environment. The basic principle is to achieve the optimization of working performance and better anti-photoelectric interference capability.

The radiation emittance increases as the temperature increases, and its peak shifts to a short wave. The infrared radiation temperature of the general military target: the turbine engine tail flame of the aircraft is about 1000K; the surface temperature of the heated aircraft is 300-400K; the temperature of the moving tank is above 400K; and the temperature of the stationary tank is about 300K, and it is located The ambient temperature is not much different. Therefore, in order to meet the purpose of imaging targets, 8~14μm long-wave infrared detectors have become the main development direction.

With the development of infrared imaging guidance, Infrared Focal Plane Array (IRFPA) has gradually replaced infrared point source detectors, and its development has matured.

3.2.3 Information processing system

In imaging guidance, image processing technology mainly performs target detection and tracking functions. In terms of target tracking, classical algorithms such as maximum contrast tracking and correlation tracking are currently used. The related tracking is mainly to complete the tracking of the target by performing matching operation in the real-time image with the target template. According to the data structure involved in the matching operation, the current matching algorithm can be divided into region-based matching algorithm and feature-based matching algorithm. In recent years, intelligent optimization algorithms such as neural network and evolutionary algorithm have also been applied in target matching. In terms of target capture and control, the main research content is automatic target recognition/detection (ATR/ATD), which is mainly used to solve the target capture problem of "post-launch" guided weapons. At present, the research on ATR algorithm at home and abroad is still in comparison. In the primary stage, multi-resolution, geometric methods, multi-algorithm multi-sensor multi-spectral fusion, and sequential image processing techniques given to the model are mainly used in the algorithm.

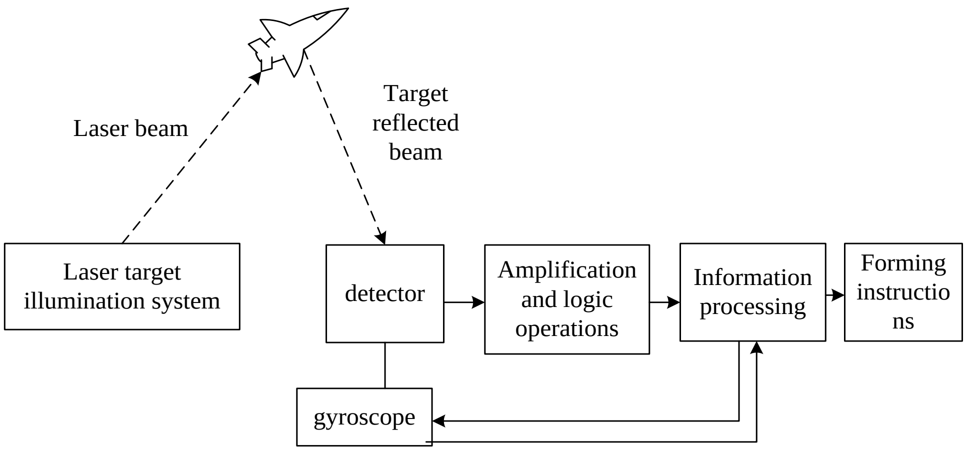

Figure 2 Laser semi-active guidance system

4. Laser guidance

4.1 Laser guidance principle

The laser is the energy that the electrons in the atom absorb the radiant energy and then transition from low energy level to high energy level, and then the high energy level falls back to the low energy level, and the frequency is the same and coherent. Therefore, the laser has the characteristics of strong directivity, narrow beam and high intensity, and is widely used in the guidance weapon by virtue of this feature.

Laser guidance is a guidance method that uses laser to obtain guidance information or transmit guidance commands to make missiles fly to the target according to certain guiding laws. It is mainly divided into semi-active homing guidance, driving guidance and command guidance. Among them, the semi-active laser (SAL) method has the advantages of flexible configuration of the emission point and the illumination point compared with the laser beam steering and the laser command guidance method, and does not require a full-range illumination target, and the range is not limited. The basic principle is that the shooter launches the missile and transmits the encoded laser beam to the target to keep track of the illumination target. The laser detector in the seeker on the missile receives the laser signal, and the amplifier further amplifies the electrical signal and generates a logical operation. The angular error signal, the information processor obtains the guiding information according to the angular error signal; the command forming device generates the guiding instruction according to the guiding information, controls the missile to fly along the correct ballistics to the target, and finally hits the target, As shown in Figure 2.

4.2 Key technology

4.2.1 Seeker

The most critical component of a laser semi-active guided weapon is the seeker. Early laser-guided bombs were generally guided by a weather vane and guided by a tracking method. At present, most laser semi-active seekers are gyro-stabilized and guided by proportional guidance. In recent years, countries such as the United States and Russia are studying low-cost strap-down seekers for simple guided rockets. The seeker requires sufficient tracking accuracy and good dynamic performance, and the range is far away. There is a large target capture domain, repeatable start, and pre-launch lock. For the seeker of the artillery-launched missile and the terminally guided projectile, the ability to withstand a large enough impact overload (eg, greater than 10 000 g) is also required.

4.2.2 Photodetector

The photodetector is the most important sensor on the seeker and is the key to obtaining the coordinate information of the target space. At present, since all laser semi-active guided weapon systems use 1.06μm wavelength, the applied photodetectors are mainly lithium-drift silicon photodiodes sensitive to 1.06μm wavelength. Common photoelectric position detectors are: position sensitive detector (PSD), four quadrant detector (QD) and so on.

4.2.2.1 Position sensitive detector

A position sensitive detector is a photodiode of a continuous single planar diffusion structure. It is based on the principle of lateral photoelectric effect and is sensitive to the energy distribution of the incident spot. When the incident light is irradiated on the photosensitive surface, a photocurrent will be generated, which flows from the incident spot to the electrode contact point and reaches the electrode contact point. The magnitude of the photocurrent is inversely proportional to the resistance between the incident spot and the electrode contact. The back end needs to access the amplification circuit, amplify the output current signal, and then calculate the centroid position of the incident spot on the photosensitive surface.

4.2.2.2 Four quadrant detector

The essence of the four-quadrant detector is a photodetector made using advanced lithography. It divides a photodetector into four blocks in a Cartesian coordinate system, corresponding to the four quadrants of the detector. It is based on the photovoltaic effect in the principle of internal photoelectric effect. When the incident spot falls into different positions of the photosensitive surface, each quadrant outputs an electrical signal of a different magnitude, and by processing the signals output by the four quadrants, the centroid position of the incident spot on the photosensitive surface can be determined.

4.2.3 Laser target indicator

Currently equipped laser target indicators, there are only a few hundred grams of hand-held, but also hundreds of kilograms of on-board indicator pods. Regardless of the indicator mounting platform and the illumination target, the requirements for it are: to ensure a sufficiently small laser beam divergence angle, and the illuminator viewing axis and the laser axis should have good parallelism. The laser target indicator emits a coded laser pulse to the target, and the seeker only considers that the target was captured after receiving the specified laser code bound before the launch. The use of coding can avoid repeated killing and accidental injury and improve the ability to resist active interference. The coded laser pulse repetition frequency should be suitably high so that the seeker has sufficient data rate.

5. Development trend

With the development of high-performance, high-sensitivity detection and components, and the rapid development of information processing and fusion algorithms, the future of photoelectric guided weapons will be developed in a multi-purpose, low-cost, and intelligent direction.

(1) Multipurpose

At present, most of the photoelectric guidance technology is designed around a certain tactical and strategic goal, with a single function and mission; the future guidance seeker will shoulder more missions, such as guidance, terminal guidance, reconnaissance and impact evaluation; The versatile use also includes multi-color, multi-mode composite guidance technology to achieve ATR function, improve the anti-interference ability of the seeker and the flexibility of the use of the seeker.

The use of composite guidance can make up for the lack of a single guidance method, greatly improving the detection probability of the target and the anti-interference ability of the seeker. For example, the United States Martin Marietta "copper snake" improved the infrared imaging / laser dual-mode seeker, when the imaging guidance mode is blocked or received interference, the laser active guidance mode is used to accurately guide the projectile to the target . Multimode composite guidance technology combines the advantages of multiple modes of conductor construction, and has greater environmental adaptability than single mode guidance, but in common aperture structure design, hood technology, electromagnetic compatibility, signal processing and data fusion, engineering miniaturization Design and other aspects will face even more severe challenges.(2)low cost

In addition to the high performance requirements, future weapon systems are also economically affordable. This requires that each unit component that makes up the weapon system minimize manufacturing costs. The technical methods for low-cost optoelectronic seeker are: using uncooled infrared imaging detectors; using a semi-strap line-of-sight stabilization system to achieve line-of-sight stability with the inertial information of the weapon system, thus eliminating the inertial measurement in the seeker Components, which in turn reduce the manufacturing cost of the seeker; the integrated design of the seeker and other electronic devices of the weapon system reduces the number of devices in the entire weapon system, thereby reducing manufacturing costs. In addition, serialization, generalization, combination and multi-functional components are used so that the same seeker can be used for different types of guided weapons and the same laser illuminator can be used for different types of laser semi-active guided weapons. Different types of missiles, bombs or shells are matched and easy to use and repair.

(2) Intelligent

Future photoelectric guidance seekers need multi-tasking, cluster cooperative combat capability and real-time task binding. Multi-tasking is to guide the leader to have the ability to track multiple targets; cluster cooperative operation refers to the situation that the seeker has battlefield situational awareness and adjusts the attack task and automatic task assignment according to the battlefield situation when using multiple/manufactured missiles for cluster attack. The ability of the real-time task binding function is to guide the projectile to bind the task data in real time through the data link between the missile and the carrier. On the one hand, it can shorten the preparation time before the missile is launched, on the other hand, the pilot can The battlefield situation temporarily changed the mission of the missile.

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