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A High-mobility and High-precision Moving Platform Photoelectric Tracking Measurement Technology

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ABSTRACT. *With the development of China's aviation industry, flight tests in various special environments are becoming more and more important, and the marine environment is one of them. Unlike traditional flight test environments, measurements in the marine environment require higher performance test systems. This paper introduces a photoelectric tracking measurement technology with high angular velocity, wide laser range, high stability and high measurement accuracy. The measurement error is analyzed, and its ability to accurately acquire data such as aircraft motion trajectory under the moving platform, as well as its stability and accuracy of operation, is proved.*

KEYWORDS: *Photoelectric tracking, Flight test, Moing platform*

1. Introduction

The photoelectric tracking measurement system is a single-station measurement system with high-precision measurement capability. It has strong intuitiveness, stable performance and reliable operation, but the measurement range is small but susceptible to weather [1]. At present, it has been widely used in flight tests and weapons tests. It has high trajectory measurement accuracy and can record test object images and is different from GPS and radar test systems. The shipborne theodolite is a new type of photoelectric tracking measurement system. It is based on the application of dynamic platform. It is mainly used to accurately measure the motion track of high-speed moving targets under the moving platform and record the target image [2]. Because it measures the single-station attitude of high-speed moving targets under the marine environment moving platform, it has higher requirements on the working environment conditions and tracking performance of the system [3-4].

The azimuth and tilting directions of the photoelectric tracking measurement system described in this paper are all driven by permanent magnet DC brushless torque motor. Redundant design is adopted in the torque design to ensure the speed

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and acceleration of the instrument and the corresponding torque reserve. The maximum angular velocity of this system can reach 100°/ s , Maximum angular acceleration can reach 100°/ s^2 , 360° infinite position bearing test and pitch measurement from -25° to +85° are possible. When the target passes through a shortcut at a high speed, it can have a large rotational acceleration and better tracking performance.

2. Measuring principle

The visible light television measurement system is capable of detecting and tracking the target to meet three conditions. First of all, the number of pixels covered by the target image is not less than 2 × 2 pixels.Then, the illuminance of the target on the target surface is greater than the sensitivity of the detector. At last, the target and background contrast at the image plane meets the video signal extraction requirements.

2.1 Target image size

In order for the image processor to reliably extract the target, the minimum size required to image the target on the detector surface should meet $N_{min} \geq [N_{min}]$. N_{min} is the number of cells covered by the minimum geometry that the target is imaging on the detector's target surface. $[N_{min}]$ is the target image required by the image processor to cover the minimum number of pixels, which should be 2 × 2 = 4 pixels, and take $[N_{min}] = 4$.

Calculated according to extremely harsh head-on conditions, the target cross-sectional area is assumed to be $1m^2$ and the diameter is 0.56 m. The number of detector target surface pixels N_{min} covered by the minimum size of the geometric image profile is:

$$\mathrm{Nmin} = (\mathrm{Dmin}\frac{f'_C}{R_C \cdot \Delta X_C})^2 \tag{1}$$

In the formula, Dmin is the diameter of the target. f'_C is the focal length of the TV system. R_C is the TV range. ΔX_C is the cell size of the detector target surface. Calculated by the above formula:

$$N_{min} = (0.56 \times \frac{500}{15000 \times 0.0074})^2 = 6.36$$

The result satisfies the condition of $N_{min} \geq [N_{min}]$, and the system can extract the target with the cross-sectional area greater than or equal to $1m^2$.

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2.2 The illuminance produced by the target on the image plane

The illuminance required to transmit the target to the visible light image surface through the atmosphere is satisfied $E_{CM}^{'} \geq$ [Emin]. $E_{CM}^{'}$ in the formula is the illuminance formed by the target at the image plane of the CCD camera, and the unit is lx. [Emin] is the minimum allowable illumination at the image plane of the CCD camera, taking [Emin]=0.5 lx.

Target illumination is:

$$E_M = E_0 \times \rho \times \sin\theta \quad (2)$$

E_0 is the sky illumination. ρ is the target reflectance. θ is the sun high angle. Calculated $E_M = 7764$(lx).

When the solar high angle is ≥15°, the observed elevation angle is ≥15°, and the angle between the target and the sun is ≥45°, the illuminance of the surface target on the target surface is:

$$E'_{CM} = \frac{1}{4} E_M \tau_1 \tau_2 \alpha \cos\theta \left(\frac{D}{f}\right) \quad (3)$$

$\frac{D}{f}$ is the relative aperture of visible light TV. τ_1 is the optical system transmittance. τ_2 is the atmospheric transmittance. θ is the angle between the observation direction and the sun. α is the diffusion coefficient. Calculated by the above formula:

$$E_{CM}^{'} = 3.28(\text{lx}) \geq [E_{min}]$$

It can be seen that the illumination of the target on the image plane satisfies the condition.

2.3 Contrast between target and background

In order to ensure a stable extraction of the target, the calculated contrast between the target and the background is satisfied:

$$C_M = \left| \frac{E'cm - E_{CB}'}{E'cm + E'_{CB}} \right| = 0.66 \geq [C_{\min}] \quad (4)$$

C_M is the contrast between the target and the background. [C_{min}] is the extraction target contrast requirement.

Therefore, the visible distance of the visible light system can reach 15km, and in the case of horizontal visibility of 5km, the visible distance of the system can not exceed 5km.

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3. Error Analysis

For TV automatic tracking, the error components mainly include tracking point error, pixel resolution error and signal processing error.

The ideal situation is that a task tracks the measurement at the same point of the target from start to finish, otherwise an error occurs. The observation angle, illumination conditions, and atmospheric transmittance cause changes in the size and shape of the target image. In the case of a target distance, tail chase or head-on tracking, this error is small for missile targets. If the target posture is the body or the power segment of the tracking target, the tracking point is difficult to stabilize. In addition, the tracking points between different sensors such as visible light TV and infrared tracking are also different. In this case, the error is relatively large. Roughly, visible light TV is estimated by σF =6″. See Table 1 for details.

Table 1. Visible light TV angle measurement error (unit: ")

error / project	Target tracking point error	Pixel resolution error	Signal processing error	Static error
formula	σ_F	$\sigma_B = \frac{\delta_H}{\sqrt{3}}$	$\sigma_C = N_C \sigma_B$	$\sigma_J = \sqrt{\sigma_F^2 + \sigma_B^2 + \sigma_C^2}$
difference	$\sigma_F = 6$	$\sigma_B = 1.76$	$\sigma_C = 1.76$	$\sigma_J = 6.49$
Note: $\delta_H = \frac{0.0074}{500}\rho = 3.05$; $N_C = 1$, f=500mm				

4. Experimental data analysis

This technology has been widely used in the aerospace field. The following figure shows the target motion trajectory measured in a certain experiment. The horizontal axis is the time value (ms), and the vertical axis is the ranging laser value (m).

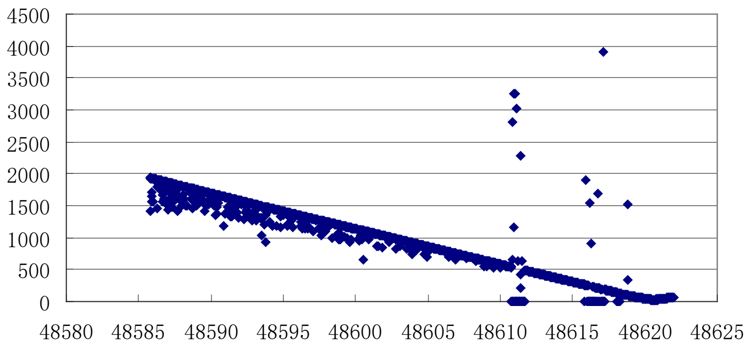

Figure. 2 Target's laser values from the theodolite

It can be seen from the above figure that when the target distance is relatively long, the laser has diffuse reflection due to air refraction. As the distance between the target and the theodolite is shortened, the bad value of the laser value is more extreme. Even the laser value appearing near 200 meters is 0. The loss of this part of the laser value has a certain adverse effect on the measurement results, but the overall trend of the laser value is in line with the actual situation. The generated bad values can be eliminated and interpolated by the later data processing software to obtain the complete laser value of the whole process. It can also be processed by other means to complement the theodolite laser value to obtain more complete and accurate motion trajectory data, such as using a high-speed camera to capture the close-range motion trajectory of the target.

5. Conclusion

As a new type of testing method, the mobile platform photoelectric tracking system will be widely used for target single-station attitude measurement in dynamic environments. This paper demonstrates its range parameter, tracking performance, etc., and uses experimental data to illustrate its feasibility and reliability. In addition, for the phenomenon of laser damage in close-range measurement, this paper also proposes improvement measures to compensate for the shortcomings of laser close-range measurement.

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