Design of a Low Altitude UAV Detection and Tracking System with Automatic Cancellation of Angle Measurement Errors

Chen Peng[a], Shi Yuejun[b], Zheng Qian[c], Liu Zhijun[d*], Li Qinghang[e], Yuan Kaixuan[f]

Unit 32382, Beijing, China

[a]chenpenglyy@163.com,[b]Paper_class3@126.com
[c]1763987144@qq.com
[d*]Corresponding author:beimingke@163.com
[e]18510016589@163.com,[f]kaixuan123@163.com

Abstract. Aiming at the complex structure and difficulty in supporting leveling operations of traditional low altitude unmanned aerial vehicle (UAV) detection and tracking systems, this paper studies an integrated turntable, which innovatively adopts a method of real-time measurement of turntable tilt angle. Automatic data compensation is performed during system calculation, filtering out the fixed errors of the turntable in the system, reducing the dependence of measurement accuracy on structural stiffness, eliminating the need for tedious support and leveling, reducing system power consumption, and improving the mobility and portability.

Keywords: cancellation, optical measurement, servo, trajectory tracking.

1 Introduction

Flight test trajectory testing refers to the measurement of the time and spatial position of moving targets in aviation weapon equipment flight tests. It establishes flight test time and spatial benchmarks in a specific real flight environment, provides target tracking image information and trajectory results, and provides qualitative and quantitative real-time monitoring and external parameter information for flight tests. It is one of the important basic technologies of flight tests. Track measurement and monitoring technology integrates multiple technologies such as target detection, tracking, digital photogrammetry, communication, monitoring, and processing[1].

All types of low altitude UAV have the advantages of flexibility, easy operation, and high cost-effectiveness. Due to the obvious infrared characteristics within the line of sight range, trajectory measurement and monitoring can be achieved through infrared imaging or television imaging. By measuring the motion trajectory of low altitude UAV, it is possible to estimate and display the trajectory, as well as calculate the target avoidance distance, in order to avoid the danger of being tracked in advance.

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The detection and tracking system for low altitude UAV usually adopts a combined methods of infrared detection[2-4] and visible light[5], which have the following problems: firstly, the structure is complex, and the turntable used for optical measurement equipment is generally above the tonnage level, which must be carried by a vehicle or trailer to work. Secondly, it is difficult to level the support and has poor reliability. In order to measure under horizontal conditions, it is necessary to support the turntable or even the trailer as a whole. The physical leveling operation is very difficult and requires a long time. Then, if there is slight wind or personnel influence, the platform will shake for tens of seconds, affecting the measurement accuracy. Leveling mechanisms often use hydraulic or mechanical methods[6], which are complex in structure, high in failure rate, and reduced in reliability. In order to solve the above problems, this article designs an integrated turntable, which innovatively adopts the method of real-time measurement of turntable tilt angle, and automatically compensates data during system calculation. Through the application of cancellation algorithms, the fixed errors of the turntable in the system are filtered out, reducing the dependence of measurement accuracy on structural stiffness, eliminating the need for tedious support and leveling, greatly reducing the weight of the body, reducing system power consumption, and greatly improving mobility and portability.

2 Structural composition

The detection and tracking system is the executing mechanism of the optical measurement system, mainly composed of a servo system, infrared thermal imager, visible light imager, signal processor, secondary power supply, etc. The electronic control system mainly includes a central control computer, display and control console, wireless data transmission, timing module, portable laser, and power module, etc. It completes the display and storage of images, the sending and receiving of instructions, the measurement of miss distance, the estimation and display of target trajectory Site calibration and other functions. The specific composition is shown in Fig.1.

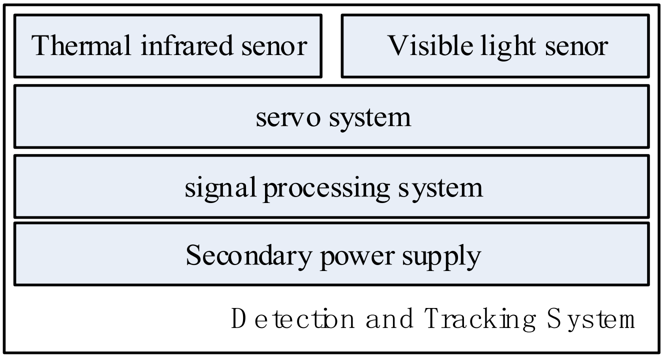

Fig. 1. Composition of Detection and Tracking System

3 Design principle of detection and tracking system

The system is mainly used to collect infrared and visible light signals, forming target signals. Then the target signals compare with the angle data in the current display control computer to form an angle error signal to drive the servo motor; According to the servo control signal of the electronic control system, the pitch drive motor and azimuth drive motor drive the pitch servo frame and azimuth servo frame. The pitch angle position sensor and azimuth angle position sensor calculate the angle data and transmit it to the display control computer. Complete initial detection and automatic tracking. The system design schematic is shown in Fig.2.

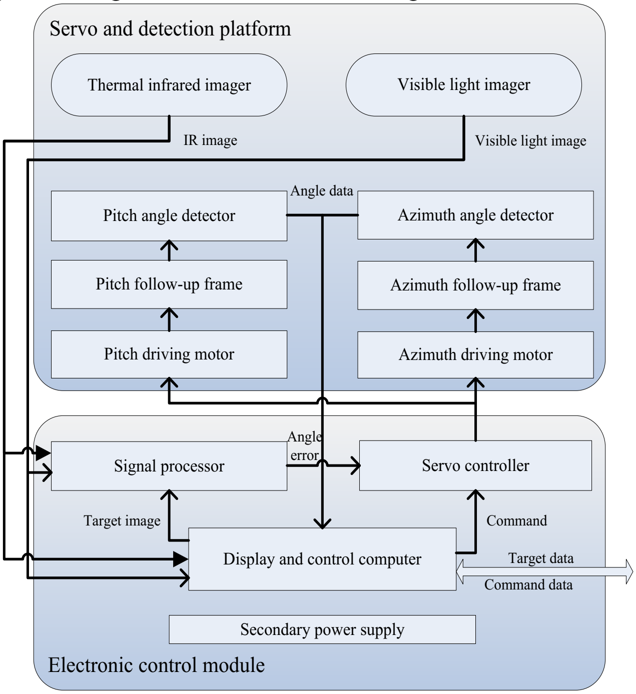

Fig. 2. System Sesign Schematic

3.1 Initial detection principle

Infrared thermal imagers have the characteristics of large field of view and stable detection and tracking, so their detection output data is used to control the servo system for closed-loop tracking. Using adaptive thresholds for target detection, the drone tracks the ejection part before takeoff. After takeoff, due to the higher temperature of the engine exhaust flame, the algorithm automatically switches the tracking point to the exhaust flame part and performs stable tracking. The initial detection schematic diagram is as Fig.3.

Taking a certain UAV as an example, the velocity of the target before takeoff is about 20m/s, and the field of view of the infrared thermal imager is 4.5 ° × 3.4 °, when the measuring station is 1.5km away from the emission point, the observable range of the infrared thermal imager is 120 × 90m, the drone can exist in the field of view for more than 3 seconds. In cases where the target signal is strong (signal-to-noise ratio greater than 5), signal processing software can generally capture the target within 5 frames. For the 50Hz infrared thermal imager in this case, the target interception time should be within 0.1 seconds. Therefore, the layout distance and field of view size designed in this scheme can meet the requirements of stable capture.

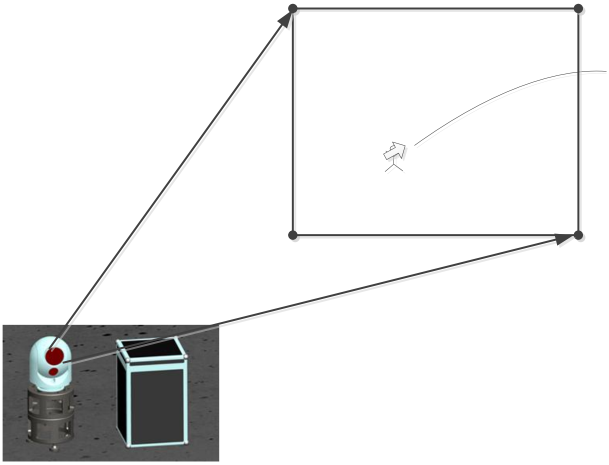

Fig. 3. Initial Detection Schematic Diagram

3.2 Automatic tracking principle

The optical measurement system can automatically complete closed-loop tracking of the target, and the tracking process is as follows: the infrared or visible light imaging system images the target and obtains image data; The image data is processed by a signal processing combination to identify and confirm the target and obtain the angular offset of the target; The angular offset of the target is amplified by a power amplifier combination to drive the servo mechanism; The servo mechanism follows the frame to drive the imaging system, so that the target line of sight coincides with the imaging system line of sight, and the target image returns to the center of the image, completing automatic tracking of the target.

3.3 System operation process

The workflow of the optical measurement system is as follows:

a) Station arrangement: Place the A and B measurement stations in the safety zone on both sides of the launch site. To ensure accuracy, the angle between the two stations and the target should not be less than 30 ° (90 ° is optimal). After the equipment is in place, select a hard ground, support the tripod, adjust the height of the legs, and make the installation surface roughly level. Install the detection and tracking mechanism on the mounting surface of the tripod, adjust the leveling handle, observe bubbles, and lock the handle when horizontal. Then open the portable packaging box containing the electronic control system, connect the corresponding cables, and proceed with the work.

b) Start: Start the power supply of the measurement station, check the working status of each combination, and power on the measurement station;

c) Calibration: Establish a relative coordinate system using the method of dual station mutual sight and distance measurement using a distance measuring machine.

Due to the close proximity, the influence of Earth's curvature is ignored. Using Station A as the main control station and Station B as the slave station, a dual station mutual aiming method is adopted. When Station A aligns with Station B, the angle is its azimuth zero, and when Station B aligns with Station A, the angle is its azimuth 180 ° . Using a laser rangefinder to measure the distance between two stations, the target plate needs to be placed at point B, and the distance can be measured by reflecting the laser beam on the target plate. Bind the measured parameters into the electronic control system. The deployment of this device is completed, with an estimated deployment time of 10 minutes per 2 people. When retracting, reverse the operation, power off, unplug the wire, remove the detection and tracking mechanism and put it into the packaging box, and include all auxiliary equipment in the portable box of the electronic cabinet. The approximate withdrawal time is 5 minutes per 2 people.

d) Preset: Guide the detection and tracking mechanism's visual axis to the (automatic or manual) target launch position, and set the system status to automatic detection status;

e) Target detection and closed-loop tracking: When a target is launched, the infrared target characteristics are obvious, and the system automatically detects, quickly locks the target, and automatically turns to tracking. Visible light has the characteristics of high resolution and precision, so its detection output data is used for target positioning and miss distance measurement.

f) Target angular position calculation: Based on the angular position sensor and target angular deviation data of the servo system, calculate the target angular position information, record it together with the acquisition time mark, and transmit it to the main station through wireless transmission;

g) Calculation of trajectory and miss distance: The main station compares the target data collected by the two stations, calculates the trajectory position and miss distance in real time through the intersection calculation algorithm of the two stations, and displays them on the display screen;

Post processing: Conduct in-depth analysis of recorded experimental data to obtain more accurate results.

4 System tracking control technology

This article independently developed servo systems, electronic control systems, and signal processors, and obtained infrared thermal imagers and visible light imagers through procurement and selection.

4.1 Detection and tracking mechanism

The detection and tracking mechanism is the executing mechanism of the measurement station, mainly composed of a long wave uncooled infrared thermal imager, a visible light imager, a servo system, a secondary power supply, and a signal processor. Infrared imaging has the characteristics of strong weather adaptability and stable detection and tracking. Therefore, the angle measurement data of the infrared system is used to control the servo system, forming a closed-loop loop; Visible light imaging has the characteristics of high resolution and high measurement accuracy.

The uncooled infrared thermal imager completes the collection, imaging, and processing of background and target infrared radiation. Output digital images of the scene for signal processors to detect and track targets; Simultaneously output standard analog videos for operators to observe.

The infrared thermal imager uses a staring focal plane array for imaging, and its working principle is that the infrared radiation of the background and target is focused on the infrared detector through an infrared optical system; The detector completes the photoelectric conversion of scene radiation; Subsequently, the amplifier amplifies, the background subtraction circuit subtracts the DC component, and the A/D performs analog-to-digital conversion to convert it into a digital signal; The non-uniformity correction and video synthesis are completed by the image processing circuit, and standard video signals are output externally for subsequent processing such as imaging display or signal detection.

The visible light imager uses a high-definition camera, utilizing the high resolution of the visible light camera to improve the accuracy of miss distance measurement. During quantitative measurement, fixed focal length (500mm) is used in optics to avoid introducing errors.The system can control the orientation and pitch motion of the detection and tracking system through the joystick. The zoom, focus, and tracking functions are completed through the function keys on the operation panel. The interface switching, image storage, and image playback functions are completed through the peripheral keys on the main display screen.

4.2 Servo mechanism

The load of the servo system is a non cooled infrared thermal imager and a visible light imager. The main functions completed by the servo system are as follows:Within the specified time, under the control of the electronic control system, preset/guide the load to the specified direction and achieve the specified accuracy requirements; Close with the information processor to drive the load to achieve precise tracking of the target. The functional block diagram of the servo system is shown in Fig. 4.

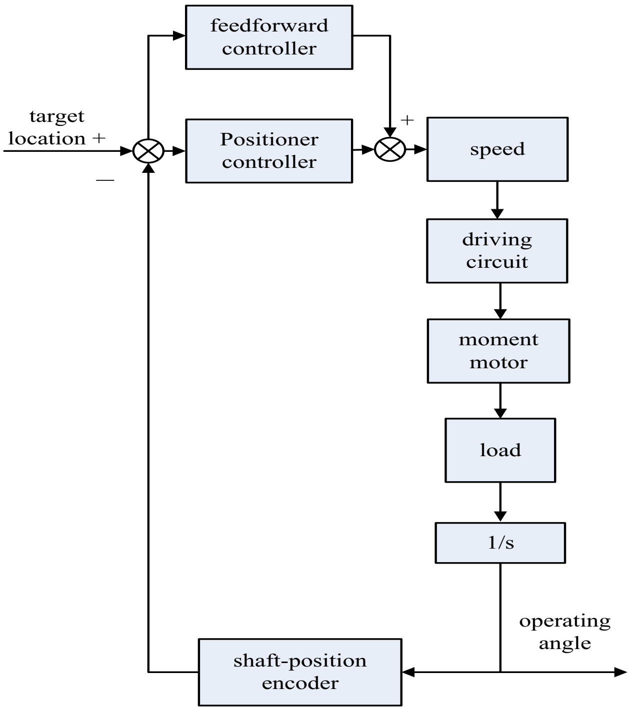

Fig. 4. The Control System Design Principleblock Diagram

4.3 Electronic control system

The electronic control system completes human-machine interaction, including motion control of the detection and tracking system, as well as data collection, processing, and display of the detection and tracking system and external devices. It has the characteristics of high integration, small size, and light weight.

Control the azimuth and pitch motion of the detection and tracking system through the joystick. Complete functions such as zooming, focusing, and tracking through the function keys on the operation panel. Complete interface switching, image storage, and image playback functions through the peripheral keys on the main display. It can display, store, and playback high-definition visible light video and standard definition infrared video signals, capture and store the current interface in image format, and record the current system status parameter data for later analysis and processing. Capable of displaying the status parameter information of the detection and tracking system, achieving miss distance calculation and target trajectory estimation and display, downloading or uploading aircraft flight data, calling and replaying aircraft flight data, simulating trajectory, synchronously describing with video, and displaying trajectory coordinates and instantaneous velocity in real-time. The control system design principle block diagram is as Fig.2.

4.4 Signal processor

The optical measurement system can automatically complete closed-loop tracking of the target, and the tracking process is as follows: the infrared or visible light imaging system images the target and obtains image data; The image data is processed by a signal processing combination to identify and confirm the target and obtain the angular offset of the target; The angular offset of the target is amplified by a power amplifier combination to drive the servo mechanism; The servo mechanism follows the frame to drive the imaging system, so that the target line of sight coincides with the imaging system line of sight, and the target image returns to the center of the image, completing automatic tracking of the target. The automatic tracking realization principle is as Fig. 5

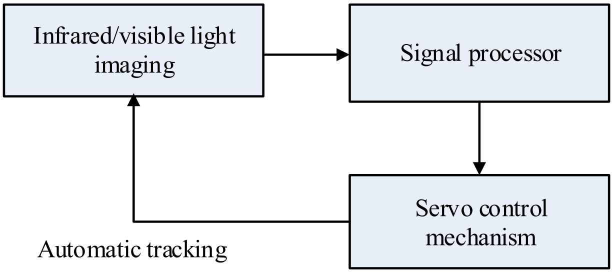

Fig. 5. The Automatic Tracking Realization Principle

The signal processor is used for real-time processing of the image output signal of an infrared thermal imager or visible light imager, for automatic target detection and tracking, or for detecting and tracking targets within a designated area using a human in loop method; In the presence of ground or sky background within the field of view, as well as optoelectronic interference, it is possible to intercept and stably track targets within the field of view, while outputting target angle deviation signals.

5 Conclusion

The detection and tracking system for low altitude UAV studied in this article has a simple structure, simple operation, and high reliability. By using software and sensors together, it changes the traditional fixed turntable system's cumbersome support and leveling process, high power consumption, large volume, and unfavorable maneuverability. The next step is to further optimize the control system and electronic system to achieve better tracking performance.

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