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Study on a Pan-tilt Control Technique for the Airship Camera Orientation

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Abstract: A pan-tilt control technique for the camera orientation of the airship is proposed. This technique is constructed by combining the airship states and the error of the image centre as a feedback. For the ground target coordinates testing system installed in airship, a two dimension pan-tilt is used to drive the camera tracking the ground target in order to catch the image of the measured target reliably. The control method of a double adaptive varying velocity PID with dead zone is proposed. Based the movement characteristic of the airship, the relationship between the movement of the target tracking and the angular velocity of the pan-tilt is analyzed; the control algorithm of the angular velocity of the pan-tilt is designed. This method make the camera continue to monitor the testing region and get the original image of the target in time. The result of experimentation shows that the method can track the ground target rapidly and steadily.

Keywords: Ground target position measurement, Airship sensors, Dual-PID self-adaptive control, Image process, Vision measurement.

1. Introduction

For the measurement of the ground target position in bigger region, the air-platform, such as hot-air balloon, airship and unmanned aircraft, sometimes are used to the to take the vision sensors as CCD cameras or TV theodolite [1] system to monitoring and track the peculiar point in the ground testing region. Although this kind of measurement technique have some advancement, for example, covering bigger test area, avoiding affection test object, etc., the limited by load capacity of the air-platform, Especially of the small airship, this platform only take light cameras, pan-tile, driver and controller of the pan-tile and the communication devices. So design a good performance of the controller used in airship is necessary. This controller can automatically calculate the controller output signal on the horizontal and vertical direction according to the deviation between the target and the ground point to be measured and the output of the angle sensors. Ref. [2] analyses the method of the measurement of the 2D and 3D coordinates of the target coordinates by using the TV measurement system, and analyses the output accuracy of the TV tracker. But in fact, real-time and accurately test the established goals of the premise and the key is to treat measuring target tracking area, thus to build a test system of tracking control algorithm is necessary. Due to the non stability of the aerial platform, often deviate from the locked area, by rotation of pan-tilt control visual sensor tracking control for the ground wide range of areas, and become one of the most active research directions in this field [3-7].

During the process of tracking and controlling, most of the control is to track the moving ground target; the main task of the vision sensor is to estimate the movement states of the moving target, which is used as feedback information to form a closed loop control, and make the air-platform fly to track the target. Because the vision sensor move and rotate with the air-platform, in the video image, the background of the target is dynamically changing, which adds the difficultly to extract the target position from the image code. To solve this problem, the researchers put forward a lot of different solutions. Ref. [8] puts forward a method that based on the motion compensation to detect the dynamic target in the image code. The core idea of this method is to use a bilinear function to describe the camera movement which causes the movement of the background image, and estimates the parameter by the position relationship of the feature point in adjacent image, so as to realize the simulation of the background movement. In Ref. [9], Han Y *et al.* estimated the speed of the target move in the image plane, and the robot movement controller is designed by using this information and Jacobian matrix to achieve the track of the target. This method can be preferably utilized to avoid the loss of target caused by the image distortion. However, Ref. [10] proposes a visual probabilistic data association filter; it can test and track the specific target in complex background. In addition, according to the ground mobile robot, Ref. [11-14] design a variety of different control strategies to achieve vision-based dynamic target tracking, and these methods usually put the estimated target states to realize the control of movement of the mobile robot. This paper mainly tracks the stillness testing region. Because of the sway of the air-platform, it is necessary to control the track, make the testing region always stay in the view field of the vision sensor, measure the target which located in the testing region.

The movement of dynamic objects in the image plane mainly comes from two aspects: the movement of the target and the camera. While the movement of static targets in the image plane is only associated with the camera motion. So in order to obtain the target status relative to the world coordinate system, it is necessary to carry out a more accurate estimation of the image change caused by the movement of the camera itself. The object to be tested does not always appear in the field of view and the location is random, so it can't provide information to estimate the change of the image caused by camera movement. To solve this problem, it adopts a method of stationary reference target estimation. This method estimates the image change which is caused by camera motion, with the help of static reference target movement information, reduces the reference of the inertial sensor noise to the estimation of target state, and realizes the tracking of the measuring region.

This paper mainly aims at the measurement the position of the ground stationary area. Due to airship moves according to the scheduled routes, and it also have a swing caused by the wind, it make the field of the vision sensor off the area to be tested. This paper, on the basis of two-dimensional reference target measurement, analyze the characteristics of airship movement and inertia of the camera pan-tile, propose the double PID adaptive control tracking strategy with dead zone of the variable speed type, induce the relationship the camera rotation angular velocity and image shift, and design the trace parameters algorithm. By the simulation and experiment, verified the correctness of this method.

2. The Structure of Measurement System

The structure of measurement system is shown by Fig. 1. The system is divided into airship-load system and ground monitoring system. There are three kinds of sensors in the airship-load system: cameras parts is used to capture the image, GPS is used to get the altitude of the camera, and the angle sensor is used to output the angles degrees formed by the light axis of camera with the horizontal and vertical. Cameras parts include CCD camera, pan-tilt, the driver and controller of the pan-tilt. The camera captures the images of the ground test area and the controller analyze and processes the angular deflection and give the signal to driver so as to drive the pan-tilt and camera to track the ground target. And same time the image and other information are transformed to ground monitoring system by the model of wireless.

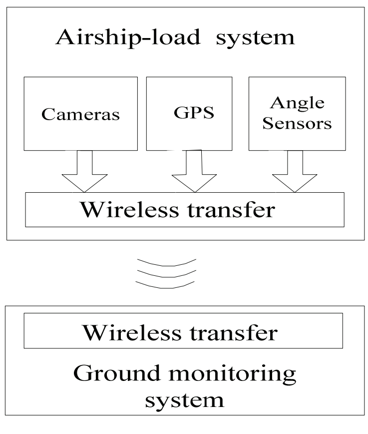


Fig. 1. The structure of measurement system.

3. The Controller Based on Airship

The ground target position measurement system uses the air-platform as the device carrier, and measures the target position with the photoelectric device. In the ground target region tracking system of vision-based aerial platform, the low altitude flying aerial platform acquires visual information immediately on the ground by the clouds terrace control system which carries the camera. The whole clouds terrace is modulated automatically based on the acquired information to keep the ground target region in the visual field of the camera. Meanwhile, the visual information is also used for the estimation of the location that included the target to be measured, which achieves the measurement of the target.

To solver the target position in the testing region is a necessity, choose a fixed target on the ground as track reference target. The air-platform revolves this reference target. The track control system is working in two methods: one is manual search and another is automatic track. Firstly finding the reference target uses the manual search method. Secondly, the pan-tilt tracks the reference target with the automatic track control system. So the testing region is monitored by the vision measurement system.

3.1. The Conventional PID Control

The PID control is one kinds of the widely used process control, which is realized, to put it simply, by proportion, integral and derivative of deviation [15-18]. PID controller is a simple algorithm based on the information estimation of “past”, “present” and “future”. In the automatic control system, PID controller possesses the advantages including easy algorithm and structure, steady performance, definite physical meaning and good robustness, which dominates the automatic control system. Nowadays, although various kinds of advanced control are developing continuously, conventional PID control is the most frequently applied in practical manufacturing process, with the following reasons like this:

1) Different kinds of advanced control are not complete practically;

2) The practical requirements can be satisfied by conventional PID control for most control object;

3) Advanced control is hard to be mastered by technical staff in company.

Motor speed is directly proportional with the size of the applied armature voltage basically, which composes the foundation of PID modulation. As the computer can only identify digital quantity and cannot calculate the continuous control formula direct, it is necessary to apply the discretization algorithm design of control law in computer control system. The motor control system is the time discrete control system, and PID algorithm is applied to the motor control system.

The scheme of theory of PID control system is illustrated in Fig. 2.

As a kind of linear controllers, it controls the controlled object through composing the control deviation e from the setting value and actual output, and composing the control value u by linear combination of deviation proportional, integral and differential [19-23].

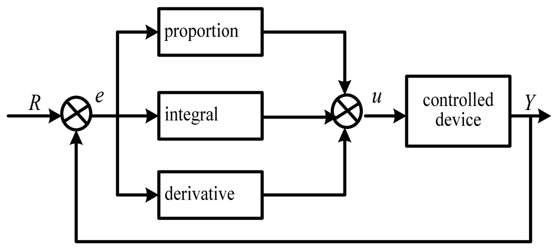


Fig. 2. The control system with PID regulator.

In the expression (1) of the digital PID speed control algorithm: U_n is the control parameter of the current system; k_p, k_d, k_i is the parameter of the proportion, differential and integration in the digital PID control algorithm; e_n and e_{n-1} are the system error of the current sample and last cycle sample.

$$U_n = k_p e_n + k_d (e_n - e_{n-1}) + k_i \sum_{i=1}^{n} e_i \qquad (1)$$

The controlling of the proportion, differential and integration coefficients are correlated, which means that they can be adjusted individually or only one or two of them can be adjusted in the controlling scheme. Their value depends on the type of the object being controlled, and also needs to be regulated in the application in order to have a better performance. In simple words, the function of the different parts of the PID controller is as following [24-25]: the proportion part reflects the system error in a certain proportion, and once here are errors it will act to suppress them. The proportional part has a great effect which will shorten the regulation time and decrease the error, but a proportion coefficient that is too large will damage the stability of the system or even destroy it. The integration part mainly works to eliminate the static error of the system and increase indiscrimination degree. The integration part will keep working until the error becomes zero and its output is always constant. The effect of the integration depends on its time constant, and a smaller time constant means a better effect and vice versa. The integration will weaken the system stability and the response speed. It is often combined with the other regulation part, such as PI or PID controller. The differential part reflects the rate of change of the system error, which means it can predict the trend of the error, thus adjust the system before the error is produced, which improve the dynamic performance of the system. Under an appropriate differential time the overshoot and adjusting time can be effectively decreased. However, the differential part would also amplitude the system noise, which means that a better differential part will threaten the systems anti-noise ability. Moreover, the differential part cannot be used without other parts, there could only be a PD or PID controller.

3.2. The Dual-PID Self-adaptive Control

As the air-platform hover, it is belongs the large disturbance environment. To track the reference target reliable, use the double adaptive PID with dead zone control method are based on the classical PID control algorithm. The block diagram of the rotational station control track shows as Fig. 3.

The whole control system is composed by two sections: manual search and automatic track. The manual search is K_1 on, K_2 off. The keyboard is controlled by operator, and the horizontal orientation $\Delta\Omega x$, pitch search signal $\Delta\Omega y$ are sent to the controller by the computer serial ports, control the reference target in the view field, and guarantee the optical axis point to the reference target. This can track the region of the target. The automatic track is K_2 on, K_1 off, the vision tracker get the image, and calculate the deviation angle $\Delta\Omega x$ and $\Delta\Omega y$ between target and center of the optical axis, send these to the main controller to form the control loop of the space position; The main controller calculates the motor speed ω_x and ω_y according to the current attitude of the air-platform which is got by the GPS, and the motor rate $\Delta\omega_x$ and $\Delta\omega_y$, sends these parameter to the main controller to form the control loop of speed rate, achieves the track control to the fixed reference target steadily.

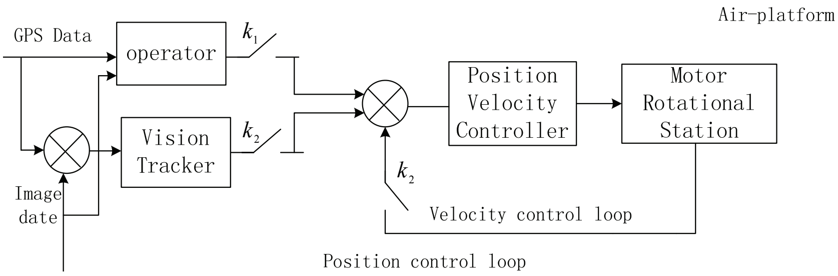


Fig. 3. The diagram of the pan-tilt control track.

In the track control condition, the digital controller uses digital PID control algorithm, and the period of the sampling is 20 ms. The signal of the TV field blanking is the signal for the system synchronous.

In the control loop of the position, need to calculate the deviation angle $\Delta\Omega x$ and $\Delta\Omega y$ between target and center of the optical axis. When the fixed reference target drift near the center of the optical axis, the control of the direction will change with unstop. This makes the motor shake. The position loop uses the PID controller with 10 % of the central angle dead zone to improve the track stability.

In the ordinary PID control algorithm, integral increment keeps invariant in the whole control process because the integral coefficient k_i is a constant. However, in the ground target location test system, the air platform has larger motion amplitude and it requires integral action to be weakened or even disappear when the system deviation is large and be enhanced when the system deviation is small.

Square up the tilt angle γ between the optical axis of the camera and the ground, this cause the size showed by the unit pixels of the camera image plane different from the real, and the smaller of the angle, the bigger of the real size showed by the unit pixels. The rotational station rotates should follow a principle: the larger γ, the faster of the angular velocity, the smaller γ, the slower of the angular velocity. When the set value of motor speed suddenly changes or the motor speed abruptly changes, it causes the step of the deviation and the PID output increases or decreases dramatically so much so that it exceeds the upper and lower limits of control variable. The actual control variable is only limited at the maximum now. The motor speed is rising, but its growth rate slows down because the control variable is restricted. Deviation lasts longer than normal circumstances in a larger deviation. So that the integral term in the PID equation continues to be cumulative. When motor speed exceeds the set value, a negative deviation appears. But due to the integral term has a considerable cumulative value, the control variable disengages the saturated zone after a considerable period of time. This is forward integral saturation, and the reverse integral saturation is similar to this. Solutions: Shorten the sampling period of the PID and tuning the PID parameters; use gearshift integral PID algorithm to improve the PID algorithm. To suffice the stability and the quick of the system, the PID track control with the shift speed and 10 % of the central dead zone to control the speed can be used.

The basic idea of the changing integration PID algorithm is to make the accumulating rate of integral term with the deviation corresponds to the size by changing it; the greater of the deviation, the slower it integral, and goes faster in the opposite case. Then the non-linear function can be defined as:

$$f(e_n)=\begin{cases}1 & |e_n|\le B\\ \dfrac{A-|e_n|+B}{A} & B<|e_n|\le A+B\\ 0 & |e_n|>A+B\end{cases} \quad (2)$$

In this case PID algorithm can be improved as:

$$U_n = k_p e_n + k_d(e_n - e_{n-1}) + k_i \sum_{i=1}^{n}[f(e_i)e_i] \quad (3)$$

While the value of f is in the range from 0 to 1. It can be proved the algorithm has entered the saturation region when the deviation is bigger than $(A+B)$, in this case, it is no longer accumulation of the integral term; when

$$B < |e_n| \le A + B, \quad (4)$$

the value of f is increased with the decreasing of deviation, the speed of accumulation goes faster until the deviation is less than B, while the speed of accumulation is up to the maximum which is 1. It is not required accurately of the algorithm to the parameters A and B, when the greater of A and B value the weaker the changing integration to the saturated inhibition, and goes stronger in the opposite case. Generally take $A = 30\%[e_n]_{\max}$, $B = 20\%[e_n]_{\max}$ in appropriation.

3.3. The Double PID Parameter Design

PID parameter tuning is setting and adjusting the PID parameters, makes the transition process of the control system achieve a satisfactory control quality. Parameter tuning has the direct relationship with quality control of the system. It is determined by process characteristics that the proportional coefficient of PID controller, integral time and derivative time. There are lots of methods to adjust the parameter of PID, summarized by two categories: one is theoretical calculation tuning method, it depends on the math model of system, theoretical calculation determines the parameter of the controller. Another is practical tuning method, it depends on the project experience, control the system directly during the experiment, and it is a simple easy way to master, and widely adopted in the engineering practice. The methods of the practical tuning mainly include critical ratio method and response curve method. The critical ratio method is a kind of cut and tries in essence. Its operation tedious and low efficiency and it may damage the device because of the improper handling. Another method is response curve method, it determines the approximate transfer function of the process by measured the step response curve of the controlled object, then use the parameters setting algorithm to tuning. The two methods have their own characteristics. The same point is experiment, then according to the project experience formula tuning the parameter of the controller. But no matter the parameter get in which way, it needs to adjust and improve in the practical operation.

4. The Control Parameter Design

According to the block diagram of the rotational station track control, to get the quick and accurate track and control, need calculate the angle of the fixed reference point offset the optical axis and the angular velocity of the reference point offset position according to the image data and GPS measure data, this can control the motor effectively through the controller.

4.1. The Parameter of the Reference Point Offset Angle

For calculate the offset angle of the fixed reference point, the position of camera and fixed reference point is showed as Fig. 4 (a), point *M* is the camera position, *h* is the height of the camera, *MA* is the main optical axis, *L* is the length of the *MA*, γ is the angle between the main optical axis and the vertical direction, B is the reference point, and need to move to point *A*, the pixel coordinates of *A* is $A'(X_A, Y_A)$, the pixel coordinates of B is $B'(X_B, Y_B)$, where

$$X_A = W/2$$
$$Y_A = H/2 \quad (5)$$

The position of image plane is shown as Fig. 4 (b). The image of point A and point B in the image plane is showed as Fig. 5, ΔnX is the number of pixel need to move toward X direction, ΔnY is the number of pixel need to move toward Y direction.

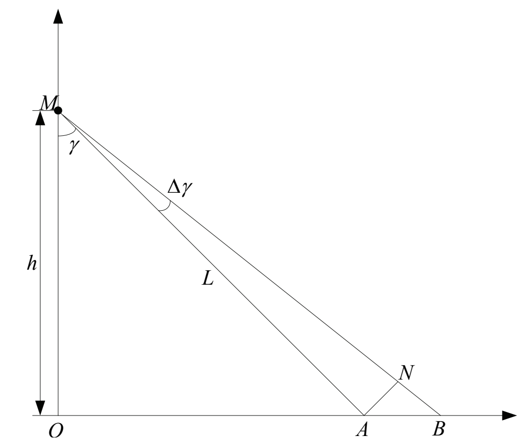


Fig. 4 (a). The relative position of camera and reference point.

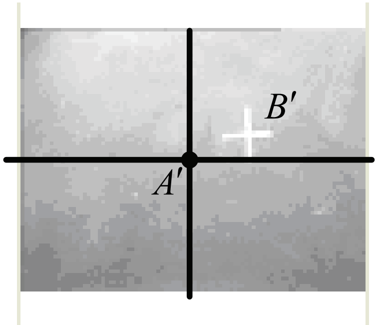


Fig. 4 (b). The image plane position of camera and reference point.

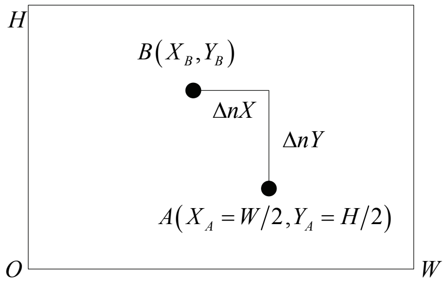


Fig. 5. Pixel coordinates.

$$\begin{cases} \Delta nX = X_B - X_A \\ \Delta nY = Y_B - Y_A \end{cases} \tag{6}$$

$$\rho = \frac{L}{f} = \frac{h/\cos\gamma}{f}, \tag{7}$$

where ρ is the magnification of camera. Suppose ΔX is the real size needed to move toward X direction, ΔY is the real size needed to move toward Y direction, μ is the pixel size.

$$\begin{cases} \Delta X = \Delta nX * \mu * \rho \\ \Delta Y = \Delta nY * \mu * \rho \end{cases} \tag{8}$$

The angle needed to rotate of rotational station is pitch angle $\Delta\Omega y$, it is $\Delta\gamma$ and horizontal angle $\Delta\Omega x$.

$$\begin{cases} \Delta\Omega x = \arctan\frac{\Delta X}{L} = \arctan\frac{\mu(X_B - X_A)}{f} \\ \Delta\Omega y = \arctan\frac{\Delta Y}{L} = \arctan\frac{\mu(Y_B - Y_A)}{f} \end{cases} \tag{9}$$

These parameters are related to the focal length of the optical system, In the track process, the change of the optical focal length will affect the gain of track systems. The focal length determine, can use camera to get the image and measure the focal length and the focal length voltage, adopt the piecewise linearization and polynomial fitting to get the relationship of focal length and the focal length voltage, according to this relationship, can get the value of the focal length real-time.

4.2. The Angle Velocity Parameter of the Reference Point Offset Position

Assume the T is the time needed to rotate elevation angle $\Delta\Omega y$ and level angle $\Delta\Omega x$, the rotational station rotate angular velocity is pitching angular velocity ω_y and level angular velocity ω_x. Because of the bigger of γ, the camera inclined, the lager displacement of the optical axis center caused by the rotational station rotate the same angle. It should satisfy:

$$\begin{cases} T_X = f_X(\gamma)T \\ T_Y = f_Y(\gamma)T \end{cases}$$

The AN is the projection of the AB in the camera image plane in Fig. 5.

$$AN = \Delta Y = (Y_B - Y_A) * u * \frac{h}{f\cos\gamma}, \tag{11}$$

$$\begin{aligned} AB &= OB - OA \\ &= \tan(\gamma + \arctan\frac{\mu(Y_B - Y_A)}{f}) * h - \tan\gamma * h \end{aligned}, \tag{12}$$

$$\begin{aligned} k_Y &= \frac{AN}{AB} \\ &= \frac{(Y_B - Y_A) * \mu * f}{\cos\gamma(\tan(\gamma + \arctan\frac{\mu(Y_B - Y_A)}{f}) - \tan\gamma)} \end{aligned} \tag{13}$$

In Fig. 6, O is camera, rectangular $ABCD$ is the ground, F is the intersection point of the optical axis of the camera and ground when the camera vertical, E is the intersection point of the optical axis and ground when the angle between camera and vertical is γ.

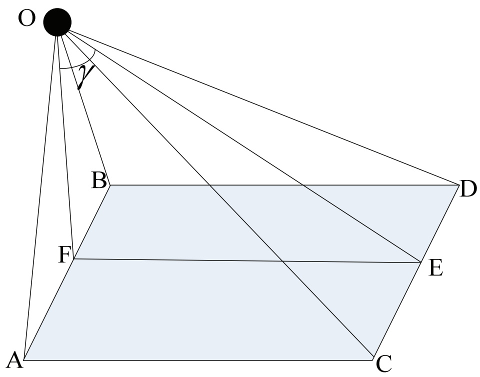


Fig. 6. The camera coordinates.

Assume the length of AB and CD is m, $OF = h$, so the length of AB and CD is $A'B'$ and $C'D'$ in the pixel coordinate:

$$\begin{cases} A'B' = \dfrac{AB*f}{OF} = \dfrac{m*f}{h} \\ C'D' = \dfrac{CD*f}{OE} = \dfrac{m*f}{h/\cos\gamma} \end{cases} \tag{14}$$

Let be:

$$K_X = \frac{A'B'}{C'D'} = \cos\gamma\,, \tag{15}$$

$$\begin{cases} f_x(\gamma) = \dfrac{1}{k_X} = \dfrac{1}{\cos\gamma} \\ f = \dfrac{1}{k_Y} \\ = \dfrac{\cos\gamma\left(\tan\left(\gamma + \arctan\dfrac{\mu(Y_B - Y_A)}{f}\right) - \tan\gamma\right)}{(Y_B - Y_A)*u*f} \end{cases} \tag{16}$$

The angular velocity of the rotational station is pitching angular velocity ω_y and level angular velocity ω_x:

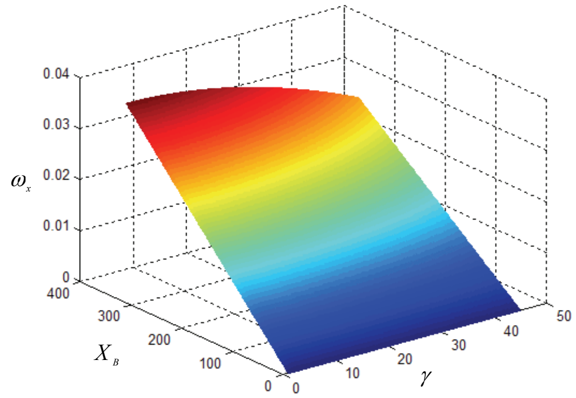
$$\begin{aligned} \omega_y &= \frac{\Delta\Omega y}{T_Y} \\ &= \frac{f\arctan(\dfrac{u(Y_B - Y_A)}{f})\cos\gamma}{(Y_B - Y_A)*u*T} \\ &* \frac{(\tan(\gamma + \arctan(\dfrac{u(Y_B - Y_A)}{f})) - \tan\gamma)}{(Y_B - Y_A)*u*T} \end{aligned} \tag{17}$$

$$\omega_x = \frac{\Delta\Omega x}{T_x} = \cos\gamma * \arctan\frac{\mu(X_B - X_A)}{f} / T \tag{18}$$

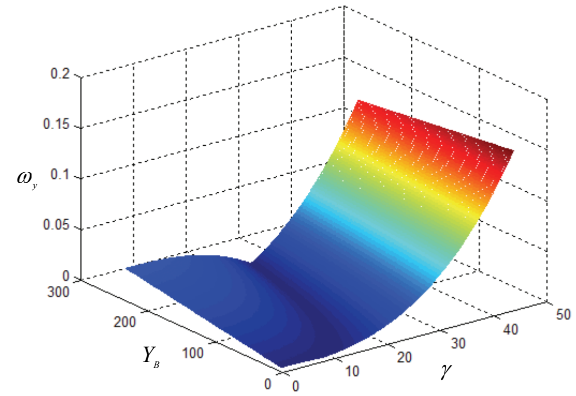
5. Simulation

According to the calculate of equation (15) and (16), the control parameter of the pan-tilt speed can be getten, and the testing region can be tracked timely. From the expression of the speed control, when the testing system is fixed, speed is related to tilt angle γ and the position of the target. Assume the change range of tilt angle γ is 0°~45° , the resolution of the camera is 640*480, the focal length is 50 mm, the coordinate of optical center is (320, 240) , the size of pixel is 0.006 mm, the relationship of the speed control ω_x , ω_y and the position of the target tilt angle γ is showed as Fig. 7.

From the Fig. 7 can get the position relation of level angular ω_x, pitching angular velocity ω_y and tilt angle γ is not the linear relation, and near the optical, the small angular velocity ω_x , ω_y needed. This control relation satisfies the requirement of speed control.



(a) The position relation of level angular ω_x and tilt angle γ .



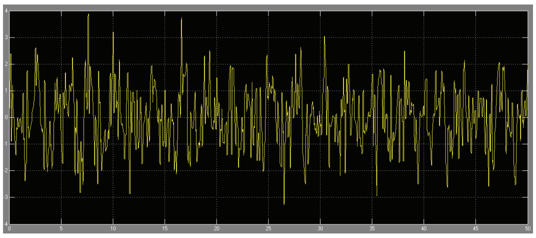
(b) The position relation of pitching angular velocity ω_y and tilt angle γ .

Fig. 7. The position relation of speed control angular velocity ω_x , ω_y and tilt angle γ .

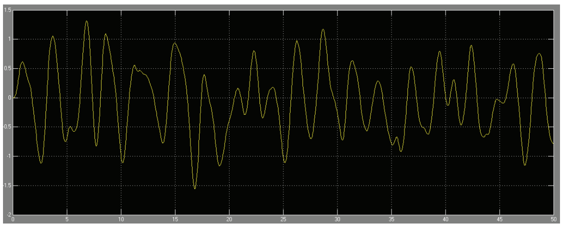
According to the control algorithm, assume the sloshing of the air-platform is the Gaussian white noise with max value 4 degree of the slip angle. As Fig. 8 (a) shows, through the simulation, we can get the track result of the view field center as Fig. 8 (b) shows, the amplitude range is [-1.6,1.8]. Through the comparison, the angle deviation gets the effective control, which can satisfy the requirement of testing region track.

According to the relation between angle and angular velocity, the wave pattern of angular velocity is shown as Fig. 9 (a), the amplitude range is[-25,32], the result wave pattern of the angular velocity control is shown as Fig. 9 (b), the amplitude range is [-3,4]. Through the comparison, the angular velocity can get the effective control, satisfy the requirement of angular velocity track.

In the actual environment, airship random swing will bring deviation interference. In order to measure the time response and steady-state characteristics of the designed controller, experiment simulation is carried out with impulse signal as interference, the respond is shown as Fig. 10, the angle deviation of position loop reached steady state within the fixed time, which is shown as Fig. 10 (a) and correspond angular velocity of velocity loop also decreases rapidly to zero, which is shown as Fig. 10 (b). Finally, the design control system can automatic track the region of reference target.

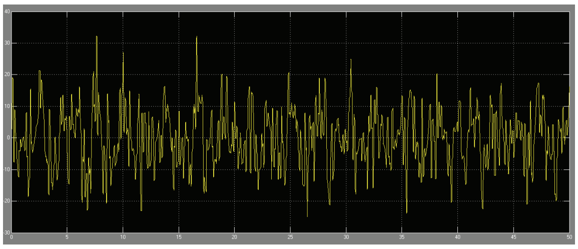


(a) The wave pattern of the angle deviation.

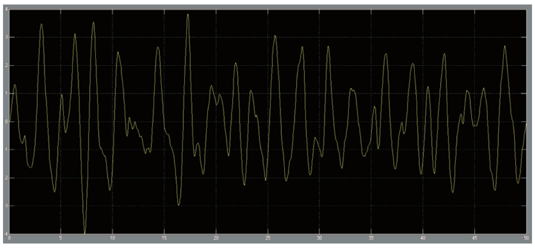


(b) The result wave pattern of the angle deviation control.

Fig. 8. The comparison of the angle deviation control.

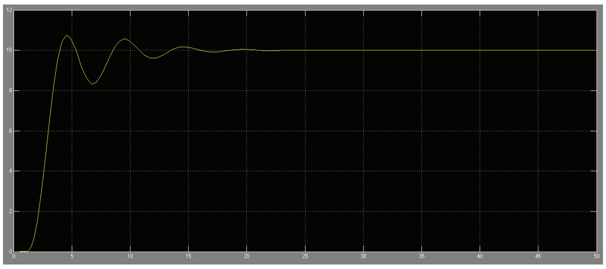


(a) The angular velocity wave pattern calculated by the angle deviation.

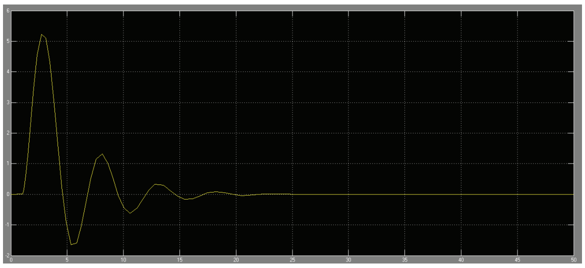


(b) The result wave pattern of the angular velocity control.

Fig. 9. The original wave pattern and the control wave pattern of the angular velocity.



(a) The angle deviation control respond of position loop.



(b) The angle velocity control respond of velocity loop.

Fig. 10. The impulse respond of the controller.

6. Conclusions

The airship ground target position testing system in this paper is researched by ourself. It is limited by the airship-load, so this condition needs all devices must light and efficient. In the condition of the movement of the airship, to guarantee to catch the image of the target, it must track the target region. By designing the ground fixed reference target, using 2D pan-tilt to load testing device, rotating the camera to track imaging the ground fixed reference target, according to the control method of the pan-tilt and the control strategy, to drive the pan-tile reliably and steadily, It can ensure to get the original image of the measured target timely, and let the camera can monitor the testing region of the measured target continuously.

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