Research on Command Generation Strategy of Roll and pitch seeker

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Abstract: The roll pitch seeker has a large field of view, which can achieve large off-axis angle attacks. At the same time, it has a simple structure and is easy to miniaturize, which is beneficial to the overall design of the missile. However, the over-tracking problem of the rolling seeker restricts her application in engineering. To solve this problem, this paper proposes a method to calculate the roll frame angle by using the angular rate of the projectile line of sight when the pitch frame angle is small. The simulation results show that this method is effective in the overhead tracking control.

1. Introduction
The position of air supremacy is particularly important in modern warfare. Air-to-air missiles with superior performance can play an important role in the seizure of air supremacy\(^1\). The battle for air supremacy is not only reflected in the performance of weapons, but also in the number of weapons mounted\(^2\), so small air-to-air missiles with advanced performance have become a research hotspot. The maximum frame angle of the pitch and yaw seeker is limited by the design of the missile's shape\(^3\). The seeker of the roll pitch stabilized platform is compact in structure, small in size and light in weight\(^4\). It meets the needs of miniaturization of air-to-air missiles. It can attack targets on the front hemisphere of the missile and meet the requirements of air-to-air missiles with a large field of view\(^5\).

There are certain technical difficulties in the engineering application of the roll pitch seeker stabilized platform\(^6\). The rotation axes of the two frames of the pitch and yaw seeker are orthogonal to each other, the miss distance output by the image processing module is based on the rectangular coordinate system, and the two channels are not coupled\(^7\), while the roll and pitch frame structure is based on the pole. In the form of coordinates, there is a coupling relationship between the two channels\(^8\). In the process of solving the polar coordinate control command with the miss distance, when the pitch frame angle is small, there is a problem that the roll frame angle command jumps\(^9\).

In response to the above problems, this paper proposes a new method of calculating the roll frame command of the pitch seeker stabilized platform. This method uses the miss distance and frame angle information to obtain the line-of-sight angular velocity, and obtains the angle command of the roll frame angle according to the direction of the line-of-sight angular velocity.
2. Roll pitch stable platform structure and its working principle

2.1. Roll pitch platform structure

Figure 1 is the structural principle diagram of the roll pitch stabilized platform used in this paper. The $x_p$ axis is the roll rotation axis of the roll pitch stabilized platform, and the $z_p$ axis is the pitch rotation axis.

![Figure 1 Schematic diagram of the structure of the rolling stable platform](image)

2.1.1. Working principle of roll pitch stable platform. For the convenience of research, the following coordinate systems are introduced.

- Projectile coordinate system $O_{x_b}y_bz_b$: $x_b$ point to the longitudinal axis of the projectile, $y_b$ in the longitudinal plane of the trajectory, upwards are positive, $z_b$ determined according to the right-hand rule.

- Roll pitch stable platform coordinate system $O_{x_p}y_pz_p$: Under initial conditions, the platform coordinate system coincides with the projectile coordinate system. The sign of the rotation angle of the platform frame is determined according to the right-hand rule.

- Line-of-sight coordinate system $O_{x_s}y_sz_s$: after the platform coordinate system rotates and around the $O_{y_p}$ axis and the $O_{z_p}$ axis, and then rotates $\varepsilon_x$ around $O_{x_s}$, where $\varepsilon_y$ and $\varepsilon_z$ are the miss distance measured by the image detector, and $\varepsilon_x$ is rotation angle of the line of sight of the projectile.

The working principle of the roll pitch stable platform is shown in the Figure 2. According to the miss distance information output by the image detector, the detector combines the current frame angle to obtain the frame angle command required to eliminate the miss distance through coordinate transformation. Control the movement of the platform through the stabilized platform servo control loop to make the optical axis point to the target.

![Figure 2 Working principle diagram of roll and pitch seeker](image)

Roll pitch seeker platform coordinate transformation to obtain the frame angle command principle: as shown in the Figure 3, there are two conversion ways from the projectile coordinate system to the line of sight coordinate system. The first is to rotate $\gamma + \Delta\gamma$ around the $O_{x_b}$ axis from the projectile coordinate system, and then rotate $\theta + \Delta\theta$ around $O_{z_b}$ to the line of sight coordinate system; the second is to rotate $\gamma$ around the $O_{x_b}$ axis from the projectile coordinate system, then rotate $\theta$ around $O_{z_b}$ to the stable platform coordinate system, then rotate $\varepsilon_y$, $\varepsilon_z$ from the stable platform coordinate system, and finally rotate $\varepsilon_x$ around the $O_{x_p}$ axis, which is coupled to the line of sight by the rotation of the roll channel, the rotation angle of the line of sight of the coordinate system.
For the second conversion approach, in the process of rotating $\varepsilon_y$, $\varepsilon_z$ from the platform coordinate system, there are different conversion matrices caused by different rotation sequences.

By first rotating $\varepsilon_z$ around $Oz_p$ and then rotating $\varepsilon_y$ around $Oy_p$, the frame angle increment is obtained as:\(^5\):

$$\begin{align}
\Delta \theta &= \cos^{-1}\left(\cos \varepsilon_z \cos (\theta - \varepsilon_z)\right) - \theta \\
\Delta \gamma &= \tan^{-1}\left(\frac{\tan \varepsilon_y}{\sin (\theta - \varepsilon_z)}\right)
\end{align}$$

By first rotating $\varepsilon_y$ around $Oy_p$ and then rotating $\varepsilon_z$ around $Oz_p$, the frame angle increment is obtained as:\(^10\):

$$\begin{align}
\Delta \theta &= \pm \cos^{-1}\left(\cos \varepsilon_z \cos \varepsilon_y \cos \theta_y - \sin \varepsilon_z \sin \theta_y\right) - \theta \\
\Delta \gamma &= \tan^{-1}\left(-\frac{\sin \varepsilon_y}{\cos \varepsilon_z \sin \theta_y + \tan \varepsilon_z \cos \theta_y}\right)
\end{align}$$

Since the miss distance $\varepsilon_y$, $\varepsilon_z$ is a small angle, the influence of the error caused by the rotation sequence can be ignored, and the first rotation sequence is more concise in form, so this article uses the first rotation sequence to calculate the frame angle increment.

For $\Delta \gamma = \tan^{-1}\left(\frac{\tan \varepsilon_y}{\sin (\theta - \varepsilon_z)}\right)$, $\varepsilon_z$ is a small angle, when the angle $\theta$ is small, the calculated $\Delta \gamma$ value will be very large, so this paper proposes a way to calculate $\Delta \gamma$ when $\theta$ is small.

First, calculate the line-of-sight angular velocity from the current frame angle and the amount of miss information given by the image detector, use the line-of-sight angular velocity to determine the direction of the target’s movement in space, and calculate the frame angle command so that the rotation axis of the pitch channel is perpendicular to the direction of the line of sight angular velocity.

The projection of the line-of-sight vector of the projectile in the platform coordinate system is:

$$[x_p \ y_p \ z_p]^T = \frac{1}{\sqrt{1+\varepsilon_y^2+\varepsilon_z^2}}[1 \ \varepsilon_y \ \varepsilon_z]^T$$

Differentiate the sight vector of the projectile to obtain the projection of the angular velocity of the projectile’s visual line of sight under the projectile system $[\dot{x}_p \ \dot{y}_p \ \dot{z}_p]^T$.

Obtain the angle between the projection of the projectile’s line of sight angular velocity in the plane of the projectile coordinate system $\gamma_n = \arctan(\dot{y}_p, \dot{z}_p)$.
Due to the special structure of the roll pitch seeker, the angle of the roll angle $\gamma_n$ or $\gamma_n + \pi$, and the rotation axes of the two pitch channels coincide. Therefore, it is necessary to compare $\gamma_n$ and $\gamma_n + \pi$ with the current roll frame angle, and take the smaller difference as the roll frame corner instructions.

3. Experimental simulation verification.

3.1. Simulation conditions 1:
In order to verify the tracking effect of the roll pitch seeker at the small pitch angle, the projectile remains motionless, the projectile coordinate system is used as the initial coordinate system, and the target position in the projectile coordinate system is $[1000 \ 5 \ (t-1)*50]$, $t < 10$, where $t$ is the simulation time, at that time $t = 1$. When the pitch angle reaches the minimum, the direction of the angular velocity of the line of sight of the projectile crosses the axis.

The frame angle command obtained by the coordinate conversion method is simply used as method 1, and when the pitch angle is small, the frame angle calculated based on the line-of-sight angular velocity is used as method 2.

The simulation curve of method 1 and the simulation curve of (method 2) are shown in the figure below.

Figure 4 Simulation conditions 1 result
It can be seen from the figure that when the pitch angle is small, when using method 2 to calculate the frame angle, the roll angle command changes little, while using method 1 to calculate the frame angle, the roll channel needs to be changed from -90 degrees to +90 degrees, And this requires a high
angular velocity of the rolling channel, which may cause the target to flicker in the image, lose the target, and cause the seeker to lose control.

3.2. Simulation condition 2:
The coordinate of the target in the projectile system is \([1000 \ 5 \cos(t) \ 5 \sin(t)], t < 10\), and the target moves in a circle around the longitudinal axis of the projectile.

![Simulation conditions 1 result](image)

Figure 5 Simulation conditions 1 result

It can be seen from the figure that the roll angle calculated by method 2 differs from the roll angle calculated by method 1 by 90 degrees, and the pitch angle differs by about 0.2°. The roll angle calculated by method 2 is used for control, and the miss distance is larger than that under the control of the roll angle command calculated by method 1, which is acceptable for infrared seekers with a large instantaneous field of view.

4. Conclusion
Based on the analysis of the command generation method of the roll pitch seeker, this paper proposes a new method to suppress the over-tracking problem of the roll pitch seeker. When the angle of the pitch frame is small, the visual line of sight angle of the projectile is calculated. The projection of the velocity in the projectile coordinate system to calculate the roll frame angle command. The tracking model of the roll seeker is established, and the command generation of the roll seeker proposed in this paper is simulated. The simulation results show that when the angle of the pitch frame is small, the angle rate of the line of sight of the projectile is used in this paper. The projection calculation method of the roll pitch frame angle command of the projectile system can effectively suppress the tracking problem of the rolling channel.
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