A Guiding Method for UAV Based on Strapdown Seeker

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***Abstract*—The relative kinematics model and the proportional guidance law was analyzed. According to strapdown seeker and unmanned combat aerial vehicle (UCAV), and the compensatory angle for strapdown seeker, the proportional guidance law was enhanced, the new guidance law was obtained which is based on line of sight angle. The result of simulation shows the advantage of the proposed guidance law in UAV with overhead attack.**

***Index Terms*—UCAV; strapdown seeker; guidance law; compensatory angle**

I. GENERAL

Unmanned aerial vehicles (UAV) can finish scheduled missions without manual intervention. Unmanned combat aerial vehicles (UCAV) has long endurance of UAV, attacks targets by missiles, and finishes reconnaissance missions. A small UCAV has a small body, light weight and low cost, and it is suitable for one man to carry.

A small UCAV commonly has visible light/infrared seeker and a small combat part. It can finish reconnaissance and searching targets by given flight path under reconnaissance mode, and after finding target it can change into attack mode and execute suicide attack. The Seeker size restricts miniaturization of small UCAV always. Along with technology developments, the strapdown seeker appears. Its sensors are connected with airframe, and mechanical structure including servo framework are removed and the sight-light angle can be obtained by mathematic calculations. The strapdown seeker reduces size and weight, and is suitable for small UCAV.

The guidance law of strapdown seeker is studied more and more. The guidance law of missiles has theoretical and practical advantages, but it takes sight-light angular rate as feedback information, and is not suitable for strapdown seekers [1]. The control law of cruise missiles is based on overloading control and is not suitable [2]. The controllers on some other UAVs are not suitable either [3].

This report improves current proportional guidance law and takes installation influence of compensatory angle into account. It is more suitable and practical.

II. BASE OF GUIDANCE LAW

A. Kinematic equation

The vertical plane is selected to analyze kinematic relations. The line between target and missile is the sight-light. The base line can be selected easily, but commonly it is the horizontal line of attack plane. Then coordinate system is established, shown in "Fig. 1".

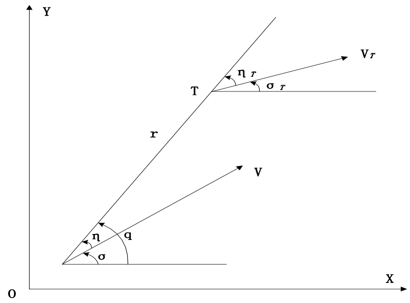

Figure 1. the sketch of kinematic coordinate system.

T	Target position
V_T	Target speed vector
V	Airframe speed vector
r	Distance between airframe and target
q	Sight-light angle (between sight-light and baseline)
σ	Angle between V and baseline
σ_T	Angle between VT and baseline
η	Angle between V and sight-light
η_T	Angle between VT and sight-light

The part of airframe speed vector on sight-light normal direction rotates sight-light, and the part of airframe speed vector on sight-light direction reduces length of sight-light. According to "Fig. 1", we can get:

$$\dot{r} = V_T \cos\eta_T - V\cos\eta$$
$$r\dot{q} = V\sin\eta - V_T\sin\eta_T$$
$$q = \sigma + \eta$$

B. Proportional guidance law

The proportional guidance law is brought out on the basis of proportional relation between rotating angular rate of airframe speed vector and rotating angular rate of sight-light. That is:

$$\dot{\sigma} = K\dot{q}$$

K should be over one at least, that is to say, rotating angular rate of airframe speed vector should be more than rotating angular rate of sight-light, so the speed vector coincides with sight-light.

UCAVs attack ground targets, so UCAV should have high precision and vertical attack. Introducing compensatory angle into proportional guidance law[1], we get:。

$$\dot{\sigma} = K\dot{q} + K_1(q - \theta_M) \quad (1)$$

Where θ_M is the expected impact angle, K_1 is the proportional coefficient of compensatory value. This method has no accurate feedback correctness, so the impact angle cannot meet the expected angle. But this method can improve that.

The proportional guidance law is easy and used widely.

III. GUIDANCE LAW OF STRAPDOWN SEEKER

Comparing with traditional stable seeker, the strapdown seeker has easy structure, low cost, anti-high overloading, small size and universal design.

The strapdown seeker needs very large instantaneous filed, that causes a lot of noise and affects stability of control and guidance system. It can obtain sight-light angle between target and airframe but sight-light angle rate needed by traditional guidance law.

In order to solve the problem of large field of view, this report adopts the solution of small field of view and compensatory angle. Because the target of UCAV is on the ground, the optical axis of the sensor looks down at a certain angle in advance. So the sensor of small field of view can scan a large range of ground targets.

A. Pose uncoupling of strapdown seeker

The uncoupling of strapdown seeker is studies a lot [2]. q_H is the horizontal sight-light angle and q_V is the vertical sight-light angle:

$$q_H = -\arctan\left({}^{\varepsilon_3}/_{\varepsilon_1}\right)$$

$$q_V = \arcsin(\varepsilon_2)$$

where:

$$\begin{aligned}\varepsilon_1 = {} & \cos\vartheta\cos\psi\cos q_{BV}\cos q_{BH} - \sin\vartheta\cos\psi\cos\gamma\sin q_{BV} \\ & +\sin\psi\sin\gamma\sin q_{BV} - \sin\vartheta\cos\psi\sin\gamma\cos q_{BV}\sin q_{BH} \\ & -\sin\psi\cos\gamma\cos q_{BV}\sin q_{BH}\end{aligned}$$

$$\begin{aligned}\varepsilon_2 = {} & \sin\vartheta\cos q_{BV}\cos q_{BH} + \cos\vartheta\cos\gamma\sin q_{BV}\sin q_{BH} \\ & +\cos\psi\sin\gamma\cos q_{BV}\sin q_{BH}\end{aligned}$$

$$\begin{aligned}\varepsilon_3 = {} & -\cos\vartheta\sin\psi\cos q_{BV}\cos q_{BH} + \sin\vartheta\sin\psi\cos\gamma\sin q_{BV} \\ & +\cos\psi\sin\gamma\sin q_{BV} + \sin\vartheta\sin\psi\sin\gamma\cos q_{BV}\sin q_{BH} \\ & -\cos\psi\cos\gamma\cos q_{BV}\sin q_{BH}\end{aligned}$$

B. Proportional guidance law of strapdown seeker

The strapdown seeker cannot provide sight-light angular rate, so traditional guidance law cannot be used here. A kind of guidance law is needed to meet the requirements of strapdown seeker.

The traditional control loop of angular rate on UAV belongs to the inner loop of pose controller, its command equation is:

$$\dot{\sigma}_m = k_p\Delta\sigma + k_d\, {}^{d\Delta\sigma}/_{dt} + k_i\int\Delta\sigma$$

The controller adopts proportion-integration-differentiation (PID) method, k_p, k_d, k_i are parameters of controller. The input value is angle error, that is:

$$\Delta\sigma = \sigma_M - \sigma$$

σ_M is command angle. The command value of angular rate is $\dot{\sigma}_m$. Because ${}^{d\Delta\sigma}/_{dt}$ cannot be measured, the noise can be amplified if the differentiation is replaced by the difference, and k_d is very small. The differentiation coefficient (k_i) is used to remove stability error and is very small commonly. If integration and differentiation are ignored, we can get:

$$\dot{\sigma}_m \approx k_p\Delta\sigma = k_p(\sigma_M - \sigma) \quad (2)$$

The model of traditional framework seeker is [5]:

$$\dot{q} = K_H K_M u = K_\varepsilon K_H K_M(q - q1) = K_\varepsilon K_H K_M \quad (3)$$

Where $\dot{q}$ is output of seeker, q is the sight-light angle, $q1$ is the light axis of seeker, $K_\varepsilon K_H K_M$ is the correlation coefficient about mechanical framework of seeker. If $K_q = K_\varepsilon K_H K_M$, equation 1, equation 2 and equation 3 are combined together, we can get:

$$k_p(\sigma_M - \sigma) = K * K_q(q - q1)$$

Therefore,

$$\sigma_M = Nq + F\{\sigma, q1\}$$

Where $F\{\sigma, q1\} = k_p\sigma - K * K_q q1$ is the function of σ and $q1$. During real calculation, σ and $q1$ are the "former step" values of airframe or sensors, if it is supposed that the time of "former step" is fixed, $F\{\sigma, q1\}$ is also a fixed value. We can get the proportional guidance law based on angle integration:

$$\sigma = Nq + C \quad (4)$$

where:

$$N = {}^{K * K_q}/_{K_p}$$

$$C = F\{\sigma, q1\}$$

C is a constant. Select start time of guidance is the fixed time, we can get the value of C.

This kind of guidance law does not include angular rate information and is suitable for strapdown seeker. It is derived from proportional guidance law and has the advantages of that.

C. Guidance law with compensatory angle

In order to solve the problem about small field of view of strapdown seeker, the compensatory angle is adopted. There is a fixed angle between airframe and sight-light angle. The fixed angle is same to the angle between airframe and seeker installed straight. So we can get:

$$\sigma = N(q - q_0) + C$$

where q_0 is the compensatory angle. Because q_0 is a constant, we get the guidance law with compensatory angle:

$$\sigma = Nq + C'$$

where

$$C' = k_p\sigma - K * K_q q1 - Nq_0$$

C' can be figured out at the beginning of guidance.

IV. SIMULATION VERIFICATION

It is supposed that the speed of UCAV is 50 meters per second, the flight altitude is 60 meters, and the target is located in the spot (100 meters, 100 meters, 0 meter). The controller adopts traditional pose control loop with guidance law from equation 4, then we start the simulation, shown in "Fig. 2". The results with different compensatory angle are shown in "Fig. 3" and "Fig. 4".

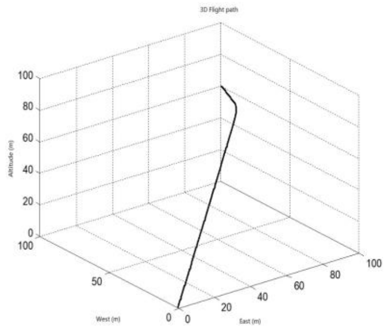

Figure 2. Guidance flight-path without compensatory angle

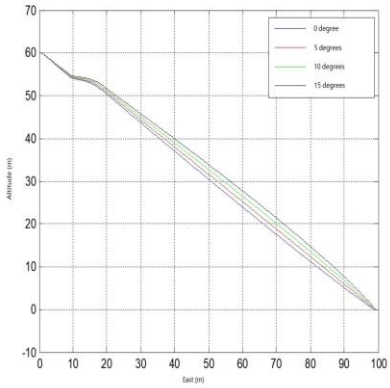

Figure 3. Vertical guidance flight-path with different compensatory angles

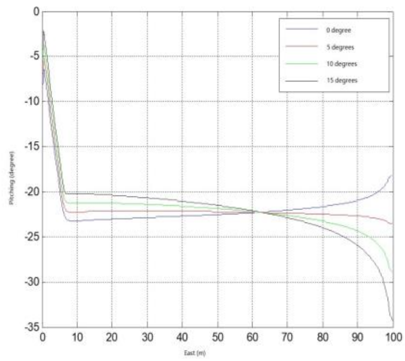

Figure 4. Curve of pitching changes with different compensatory angles

The path of the guidance law with compensatory angle is different from the path of standard guidance law, but both can finish target impact. The path difference of different compensatory angles is that, the larger the compensatory angle is, the higher the path is and the larger the dive-angle is. "Fig. 4" shows that the guidance law with compensatory angle improves the impact angle.

V. CONCLUSION

This report introduces a kind of guidance law suitable for UCAV based on standard proportional guidance law. The result of simulation and experiments shows that the guidance law meets the requirements of UCAV. The guidance law has high accuracy, effect and practicability.

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