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Implementation Of Flight Control System Based On Kalman And PID Controller For UAV

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Abstract: Kalman and PID controller are used to design UAV (Unmanned Air Vehicles) formation flight control system for speed and pitch angle. UAV adjusted the PID parameters to realize control stability of UAV flight. The simulation results will show that Kalman and PID controller have better dynamic performance than the traditional controller in respect of simpler design, higher precision, easier implement, etc. At the same time, the control effect will be significantly improved. In addition, Kalman & PID control is superior in short transition, good stability, anti-disturbance, good control and etc, it also fulfills the requirement of real-time and accurate control.

Index Terms: Flight Control System, Kalman Filter, PID Controller, UAV, MATLAB.

1 INTRODUCTION

UAV is used in the main battlefield of the war because of fewer casualties, better hidden, more flexible and less military expenditure.It is improved the hit rate and reduced wing resistance of the formation flight and improved operational efficiency and reduce energy consumption. It is also important to control the flying posture of UAV as to make formation flying better, including the relative position control and attitude control of the UAV. Close cooperation algorithm and the anti-collision schemes are implemented to design UAV formation flight control system. UAV is used in many applications; military application, aerial archaeology, environmental protection (measurement of air pollution and forest monitoring) and traffic congestion analysis, etc. In Figure.1, y_v is the output signal contaminated by noise and y_e is the output signal modified by Kalman filter. The input signal is a step signal. The w (t) is amplitudes of the interference controlling signal and v (t) is noise measurement signal. UAV are aerial vehicles capable of flight without an on-board pilot. UAV itself is multi-input, multi-output and non-linear system. UAV is important to maintain the relative distance between the wing planes and lead planes (forward, lateral, vertical).It can eliminate the static error by combination of Kalman & PID.It can ensure the system design simple, robustness strong, reliable by Kalman & PID. Kalman filter is used to filter the detection signal noise and extract the true signal as feedback .PID controller calculate error as the difference between a measured process variable and desired set-point. PID can solve the existing problems and improve the dynamic response of UAV. The objectives of this research are to design UAV formation flight control system using combination of Kalman & PID, to study regulation quality variation under interference of strong noise, to adjust UAV flight stability by controlling PID controller, to remove signal noise or disturbance by Kalman filter.

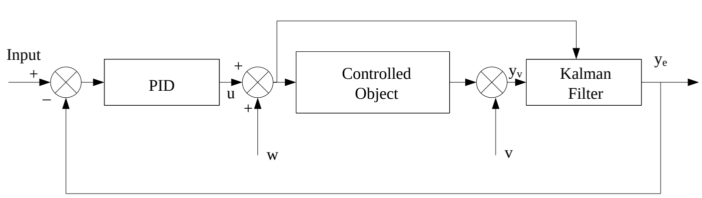

Figure.1. Kalman and PID Control System

2 MATHEMATICAL MODEL OF THE UAV

In this study the longitudinal motion of the Bluebird is investigated. Longitudinal variables for UAV model are expressed in Fig.2. We can find the longitudinal equations motion for the UAV by linearizing the equations for bluebird UAV flight.

The longitudinal state model is given below:

$$\begin{bmatrix} \Delta\dot{u} \\ \Delta\dot{w} \\ \Delta\dot{q} \\ \Delta\dot{\theta} \end{bmatrix} = \begin{bmatrix} X_u & X_w & 0 & -g \\ Z_u & Z_w & u_0 & 0 \\ M_u + M_{\dot{w}}Z_u & M_w + M_{\dot{w}}Z_w & M_q + M_{\dot{w}}u_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \Delta u \\ \Delta w \\ \Delta q \\ \Delta\theta \end{bmatrix} + \begin{bmatrix} X_{\delta e} \\ Z_{\delta e} \\ M_{\delta e} + M_{\dot{w}}Z_{\delta e} \\ 0 \end{bmatrix} [\Delta\delta_e]$$

$$y = [0 \quad 0 \quad 0 \quad 1] \begin{bmatrix} \Delta u \\ \Delta w \\ \Delta q \\ \Delta\theta \end{bmatrix} + [0][\Delta\delta_e] \quad (1)$$

Where $\delta_e$is the elevatorinputs, u is the forward velocity, w is the vertical velocity, q is the pitch rate, θ is the pitch angle and X_u,X_w,X_q, Z_u, Z_w, Z_q, M_u, M_w, $M_q$and $X_{\delta e}$, $Z_{\delta e}$, $M_{\delta e}$ are the dimensional stability derivatives.

3 TRANSFER FUNCTION OF AIRCRAFT

We consider the aircraft flying in a straight and level flight at with a velocity. To obtain the transfer function of the aircraft, it is necessary to define the positive deflection of the elevator. The longitudinal transfer function leads to the following approximations of the phugoid and short period oscillation. The phugoid oscillation takes place at an almost constant angle of attack α. As the phugoid oscillations are of long period mode, θ is varying quite slowly, therefore, the inertia forces can be neglected. The phugoid approximation is not satisfactory for simulation. The short period oscillations occur at an almost constant flight speed u, and change angle of attack α, because force in the x direction contribute mostly to change in the flight speed. The short period approximation has very good agreement in the vicinity of the natural frequency of the short period oscillations. It is more accurate than phugoid oscillations. Therefore, short period approximation can choose for the simulation of the aircraft elevator transfer function. The short-period longitudinal motion for UAV model is expressed as follow:

$$\begin{bmatrix}\Delta\dot{\alpha}\\ \Delta\dot{q}\end{bmatrix} = \begin{bmatrix}\frac{Z_\alpha}{u_0} & 1\\ M_\alpha + M_{\dot{\alpha}}\frac{Z_\alpha}{u_0} & M_q + M_{\dot{\alpha}}\end{bmatrix}\begin{bmatrix}\Delta\alpha\\ \Delta q\end{bmatrix} + \begin{bmatrix}\frac{Z_{\delta e}}{u_0}\\ M_{\delta e} + M_{\dot{w}}Z_{\delta e}\end{bmatrix}[\Delta\delta_e] \quad (2)$$

The short period longitudinal equation for bluebird UAV is

$$\begin{bmatrix}\Delta\dot{\alpha}\\ \Delta\dot{q}\end{bmatrix} = \begin{bmatrix}-5.3293 & 1\\ -22.2728 & -4.5916\end{bmatrix}\begin{bmatrix}\Delta\alpha\\ \Delta q\end{bmatrix} + \begin{bmatrix}-0.5269\\ -32.9831\end{bmatrix}[\Delta\delta_e] \quad (3)$$

The longitudinal transfer function for short period mode can be approximated by function:

$$\frac{\theta(s)}{\delta e(s)} = \frac{-32.98s-164.04}{s^2+9.92s+46.74} \quad (4)$$

The system uses a steering inertia model transfer function:

$$G_1(s) = \frac{-1}{0.1s+1} \quad (5)$$

This pitch angle can be drawn to open loop system transfer function:

$$G_2(s) = \frac{329.8s+1640.4}{s^3+19.92s^2+145.94s+467.4} \quad (6)$$

The short period mode occurs in a smaller time period where the change in pitch and attack angles are significant and it also has high damping factor. The longitudinal roots show a stable motion. The short-period approximation is more stability than the phugoid approximation.

4 Controller Design for the UAV Model

Most commercial autopilots use the traditional PID controllers. Because they are easy to be implemented with the small UAV platforms. But PID controllers have limitations in optimality and robustness. Besides, it is also difficult to tune the parameters under some circumstances. The basic idea of PID control is to combine the proportional, integral, differential coefficient of basis by linear combination to control the controlled object. By using PID control, the system performance depends on the three appropriate parameters, PID control law is

$$u(t) = k_p[e(t) + \frac{1}{T_I}\int_0^t e(t) + T_D\frac{de(t)}{dt}] \quad (7)$$

where kp is scale factor, TI is the integral time constant; TD is the derivative time constant. In most cases, PID controller has good effect in controlling, but in the special circumstance of high speed and high altitude flight, the influences of air flow, pressure, temperature may cause a dramatic disturbance. The practice proves that PID controller cannot properly complete the control tasks under such circumstance, particularly in the flight which needs strict requirements of control quality. If overshoot, slow response, long adjusting happen in control process, the flight formation will be in the confusion or even collision accident. So, UAV formation flight has high risk by using PID control itself. The simulation result show the feasibility of the method, and the formation members led to higher navigation accuracy. But because the wing planes use the errors of lead planes as the true value to result in static errors.

5 Kalman Filter for UAV State Estimation

If the signal and noise are the random process of multi-dimensional non stationary random, their time variability and the power spectrum is not fixed to result in difficult to automatically adjust the PID controller parameters and desired control effect cannot be achieved. The Kalman filter is used to filter the detection signal noise that is to remove noise, exact the true signals feedback. The Kalman filter is applicable not only to estimate the smooth scalar system, but also give the minimum variance unbiased estimating to the multi- input and non- stationary multi-output time varying system. In addition, the Kalman filter algorithm is a recursive algorithm, especially suitable for running on computer. Kalman filter uses state equations (state space matrices) and initial values to calculate the residue and gain values and to estimate the real signal value. The steps of the Kalman filter can be explained using linear discretized state and measurement equation:

$$x(k+1)=A\,x(k)+Bu(k)+G\,w(k)$$

$$y(k)=Hx(k)+v(k) \quad (8)$$

In the state equation x(k) is the state vector of the system, A is the system transition matrix, u(k) is the input vector, B is the control distribution matrix, w(k) is the random Gaussian noise vector (system noise) with zero mean and known covariance structure, G is the transition matrix of the system noise. In the measurement equation y(k) is the measurement vector, H is the measurement matrix, v(k) is the measurement noise vector with zero mean and known covariance structure. There is no correlation between the system noise w(k) and measurement noise v(k). The Kalman filter tries to estimate real signal from the signal with disturbance which has Gaussian distribution and decreasing the value between two signals.

6 Simulation of PID Controller and Kalman Estimator

The model of longitudinal motion can be described using Euler approach. Thus, short period longitudinal motion is applied in this paper. The new A and B matrices to be used in the filtering approach can be found by

$$x(k+1)=A\,x(k)+Bu(k)+G\,w(k)$$

$$y(k)=Cx(k)+Du(k) \quad (9)$$

The short period longitudinal equation for bluebird UAV model can be given as follows:

$$A = \begin{bmatrix} -19.92 & -145.94 & -46.74 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$C = [0 \quad 329.8 \quad 1640.4]$$

$$D = 0 \qquad (10)$$

The disturbance with Gaussian white noise characteristics generated by Matlab commands is applied to the real values found using bluebird UAV model. Kalman filtering technique is then applied and its effectiveness is shown. In the real disturbances in measurement and process is usual and have an effect on the controller. Thus, using a filtering technique is important. The values of the states can be calculated. The disturbance on the states of course must be determined firstly and applied to the system. Finally Kalman filter can be applied to the system with the disturbances to develop and effective controlled. To do this a Matlab code is written. Root locus for longitudinal transfer function is shown in Fig.3; all characteristic roots are in the left half plane, so the system is stable.

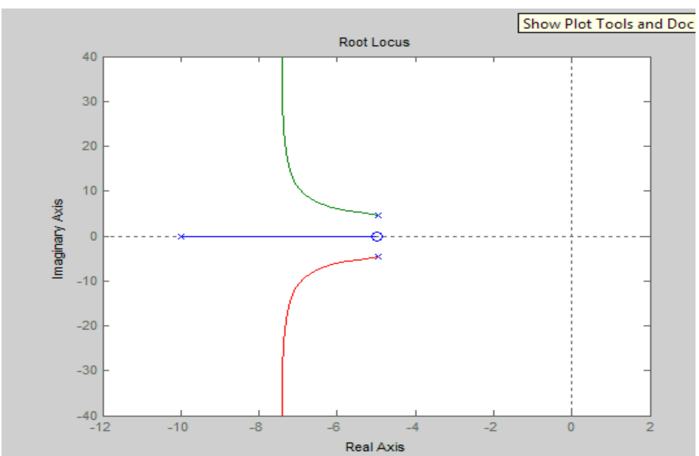

Fig.3; Root locus of longitudinal control system

The controlled object UAV model can be controlled by the PID controller without using a filtering technique. Therefore, the result with PID controller will cause a little disturbance. Following figure shows the result of UAV model with causing errors.

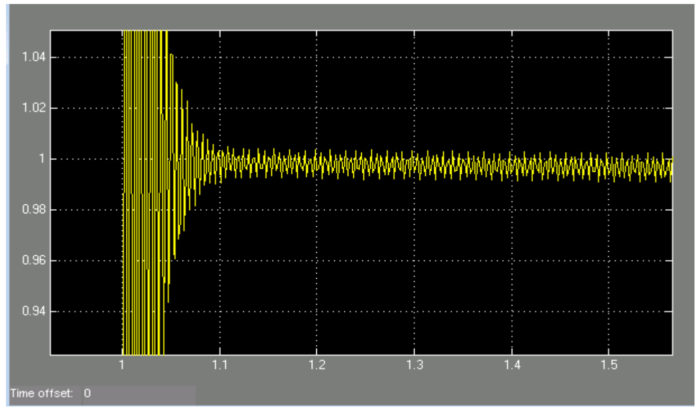

Fig.4; The longitudinal step response of PID control without filtering

The Kalman filter that works as an optimal observer is estimating the new values of the states correctly and decreasing the error. The extended Kalman filter cannot have the same value between the actual value and the estimate value for pitch, roll and yaw rates of bluebird UAV model.

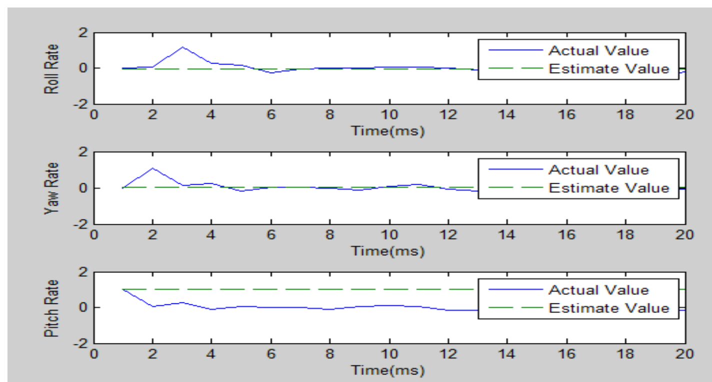

Fig.5; Difference between estimate and actual values for Roll, Yaw and Pitch rates (EKF)

The unscented Kalman filter can have more accurate than EKF. Therefore, the UKF can almost have the same value between the actual value and the estimate value for pitch, roll and yaw rates of bluebird UAV model.

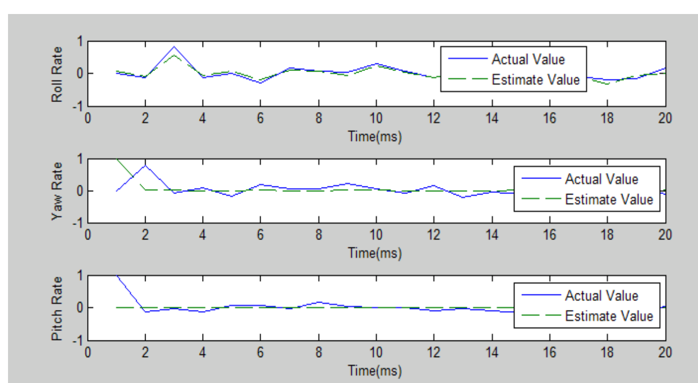

Fig.6; Difference between estimate and actual values for Roll, Yaw and Pitch rates (UKF)

The PID control system and Kalman filtering technique for UAV model is described in this paper. The whole of the autopilot system includes several parts like state observer, state estimator and flight controller. Many different techniques have been applied for UAV control and particularly for autonomous helicopter control. Both linear and nonlinear control techniques have been applied for model-based control. In this paper, PID control technique is used for designing UAV model. Mathematical model for longitudinal motion of UAV control can be evaluated and then UAV model controls using PID control method.The PID control method can be utilized in the multi-plane formation flight. Because of controlling quality deterioration caused by the detection signal polluted by the noise, it ensures the minimum overshoot in the control system. Finally, this paper compares the relative estimation accuracy of UKF compared to EKF for linear state space models with nonlinear measurement. This leads to the conclusion of UKF being a more robust estimator than EKF estimator.

7 Conclusion

Using combination of Kalman & PID was achieved little overshoot, short transition, good stability, anti-disturbing using combination of Kalman & PID.UAV can avoid collision accident and accurate control. This simulation results are shown forward moving control and vertical moving control. When UAV receives the throttle input for forward moving control, the thrust will cause due to throttle control. So, the output will appear forward distance because of forward velocity. When UAV achieves the elevator input, the output will produce vertical distance because of pitch rate. Because of controlling quality deterioration, it ensures the minimum overshoot in the control system. Applying Kalman filter into the traditional PID control system can be utilized in the multi-plane formation flight because greater reliability and more values in engineering. It has the advantages of both, which are short transition, good stability, anti-disturbing and etc; it also fulfills the requirements of real time and accurate control.

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