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Attitude Control of Helicopter using Fuzzy Inference Technique

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Abstracts

The helicopter system is non-linear and complex. Futhermore, because of absence of an accurate mathematical model, it is difficult accurately to control its attitude. But we can control the non-modeled system with the uncertainty and unstructre using the fuzzy control algorithm. Therefore, we apply optimized fuzzy controllers for the control of its elevation angle and azimuth one using expert's intuitions and knowledges. The simulation and experimental results of the hellicopter simulator CE150 with MATLAB shall be introduced.

Keywords Helicopter, Attitude, Fuzzy Controller

1. Introduction

There are many new and advanced techniques to control the large-scale, nonlinear, naturally unstable, MIMO and highly cross-coupled systems such as helicopter. Specially, the accurate attitude control of helicopter is very difficult since the perturbations of system parameters are given according to various environmental conditions.

Therefore, the mathematical modeling of plant is very difficult. If the classical control technique such as PID control is applied to the attitude control of helicopter, the stability of control system substantially shall be deteriorated by load fluctuations.

But even the non-modeled system with the uncertainty and unstructure can be controlled by the fuzzy control algorithm. based on the expert's intuitions and knowledges. Therefore, we apply a fuzzy technique to the control of its elevation angle and azimuth. The simulation and experimental results of the helicopter simulator CE150 with MATLAB shall be introduced.

Specially, in this paper, it is shown that the optimized fuzzy controllers for attitude control of helicopter were superior to the conventional PID controller through the results of simulation and experiment.

2. Mathematical Modelling of Helicopter

2.1 Dynamics equation of helicopter

The a typical helicopter is shown in Fig.1. In Fig.1, θ_1 is a vertical angle, θ_2 is a horizontal one (azimuth angle), ω_1 is an angular velocity of a main rotor and ω_2 is an angular velocity of a tail rotor.

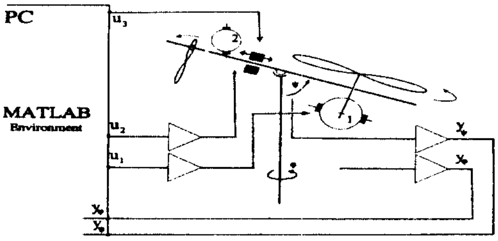


Fig. 1 Sketch Description of Model Helicopter

To derive the dynamic equation of helicopter, we use Lagrange's equation and the force balances, under the assumptions that the lift force of a helicopter is proportional to the square of the velocity of a main motor and the speed of helicopter can be neglected comparing with the speeds of main motor and tail one. Therefore, the torque balance in the vertical plane acting on the helicopter body is described as follow.

$$I\ddot{\theta}_1 = K_{\omega 1}\omega_1^2 + \frac{1}{2}\, ml\dot{\theta}^2 \sin\theta_1 - (C_{\theta 1}\, sign\, \dot{\theta}_1 + B_{\theta 1}\dot{\theta}_1) - mgl\sin\theta_1 + K_G\dot{\theta}_2\omega_1\cos\theta_1$$

where,

$K_{\omega 1}$: air resistance coefficient $C_{\theta 1}$: coulomb-friction coefficient

$B_{\theta 1}$: viscous-friction coefficient m : mass

g : gravitational acceleration l : the radius of main motor

K_G : gyroscopic gain

I : inertia moment of the helicopter body around horizontal axis

The torque balance in the horizontal plane, taking into account a main forces acting on the helicopter body in the direction of θ_2 angle, is a follow.

$$I\sin\theta_1\, \ddot{\theta}_2 = K_2\, l_2 \sin\theta_1\omega_2^2 - (C_{\theta 2} sign\dot{\theta}_2 + B_{\theta 2}\dot{\theta}_2) - \tau_r \qquad (2)$$

In eq.(2), K_2, $C_{\theta 2}$ and $B_{\theta 2}$ are constant, l_2 is the radius of a tail motor, and τ_r is the reaction torque of a main motor. Fig.2 is a block diagram of model Helicopter.

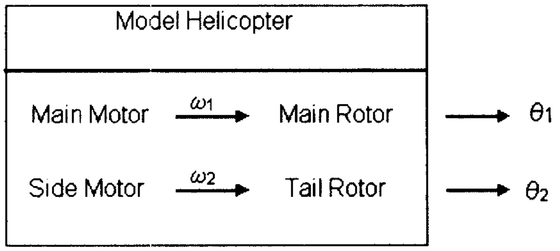


Fig.2. Block diagram of Model Helicopter

2.2 The mathematical modeles of main motor and side one

The main motor and the side one which are attached to helicopter body are to drive the main rotor and the tail one. In the mathematical model of in DC motor, neglecting.

The armature inductance of DC motor is neglected, but the coulomb friction and the resistive torque generated by rotating propeller in the air are significant. Therefore, the equation for the torgue τ_j of DC motor generated by the armature current i_j is described as follow.

$$\tau_j = I_j\omega_j + C_j sign(\omega_j) + B_j\omega_j + B_{pj}\omega_j + D_{pj}\omega_j^2 \qquad (j=1,2) \qquad (3)$$

$$i_j = \frac{1}{R_j}(U_j - K_{bj}\omega_j),\ \tau_j = K_{ij} i_j \qquad (j=1,2) \qquad (4)$$

By using eq.(3) and eq.(4) the block diagram of DC motor is shown in Fig.3. In Fig.3, subscript j = 1 means a main motor and j = 2 a side motor, I_j the inertia of DC motor, C_j the coulomb-friction coefficient of motor, B_j the viscous-friction coefficient of motor, B_{pj} the air resistance coefficient(laminar flow), D_{pj} the air resistance coefficient (turbulent flow), R_j the armature resistance of motor, U_j the armature voltage of motor, K_{bj} the counter-emf constant and K_{ij} the torque constant.

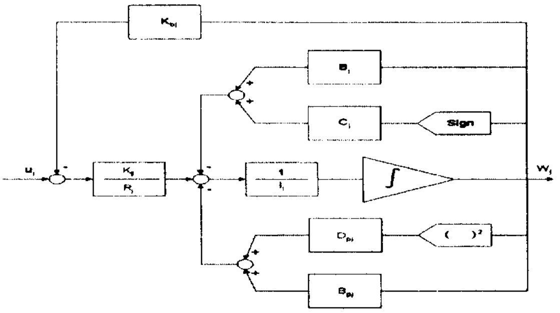


Fig.3. Block diagram of DC motor

3. Design of controller

The block diagram which consider the effect of a mechanical coupling between motors is shown in Fig.4. Kc is the coupling gain.

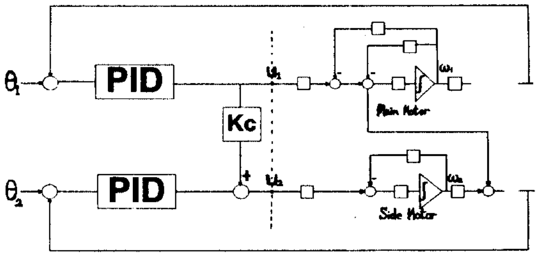


Fig. 4 Block diagram for the influences of Mechanical-coupled system

3.1 PID Controller

The output of PID controller is as follow,

$$U_j(s) = K_j[(W_j(s) - Y_j(s)) + \frac{1}{sT_i}(W_j(s) - Y_j(s)) - \frac{sT_d}{1+\frac{sT_d}{N}} Y(s)] \qquad (5)$$

In eq.(5), T_i is the integral time, T_a the derivative time, $Y_1(s) = \theta_1(s)$, and $Y_2(s) = \theta_2(s)$.

Eq.(5) is discretized as follow.

$$U(k) = P(k) + I(k) + D(k) \tag{6}$$

where,

$$P(k) = K(w_j(k) - y_j(k))$$

$$I(k) = I(k-1) + \frac{T_s}{T_i} P(k-1)$$

$$D(k) = \frac{T_d}{T_d + NT_s} D(k-1) - \frac{T_d}{T_d + NT_s}(y_j(k) - y_j(k-1))$$

T_s : sampling time.

3.2 Fuzzy Controller

The basic structure of the fuzzy logic controller is given into four part as Fig.5.

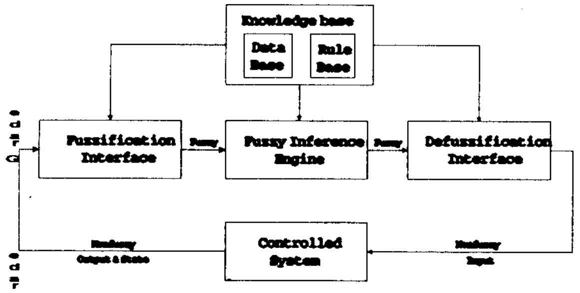


Fig. 5 Basic structure of a Fuzzy Logic Controller system

In this paper, the fuzzy inference is operated by the defuzzication by using the center method of gravity, as Fig.6.

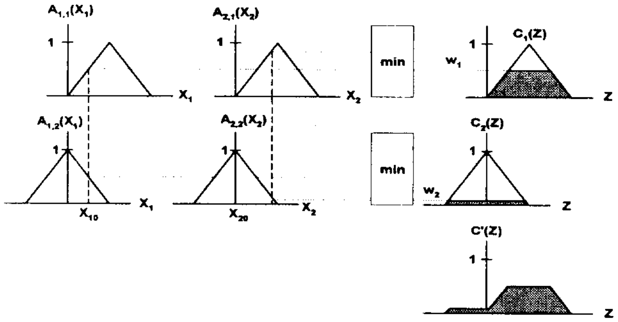


Fig. 6 Inference process of fuzzy inference method

3.2.1 The optimized fuzzy controller for a elevation angle

The optimized fuzzy control rules for the desired elevation angle are shown in table.1.

Table 1 Fuzzy Rules for Elevation Angle

ω_1 \ θ_1	NB	NS	ZO	PS	PB
NB	PB	PB	PS	PS	ZO
NS	PB	PS	PS	ZO	NS
ZO	PS	PS	ZO	NS	NS
PS	PS	ZO	NS	NS	NB
PB	ZO	NS	NS	NB	NB

NB : Negative Big NS : Negative Small ZO : Zero PB : Positive Big

PS : Positive Small θ_1 : Elevation Angle ω_1 : Angular Velocity

3.2.2 The optimized fuzzy controller for azimuth angle

The optimized fuzzy control rules for the desired azimuth angle are shown in table.2.

Table 2 Fuzzy Rules for Azimuth Angle

ω_2 \ θ_2	N	Z	P
N	P	P	Z
Z	P	Z	N
P	Z	N	N

N : Negative Value Z : Zero Value P : Positive Value

θ_2: Azimuth Angle ω_2: Angular Velocity

The membership functiones for control the vertical and azimuth angle are shown in Fig.7 and 8, respectively.

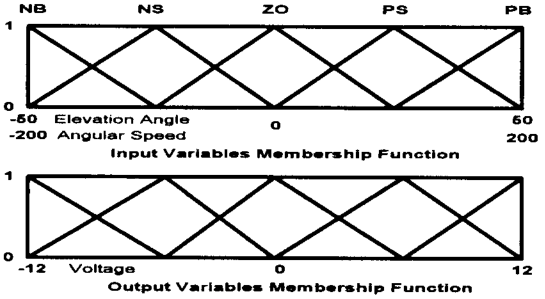


Fig.7. Membership Functions for Elevation Angle

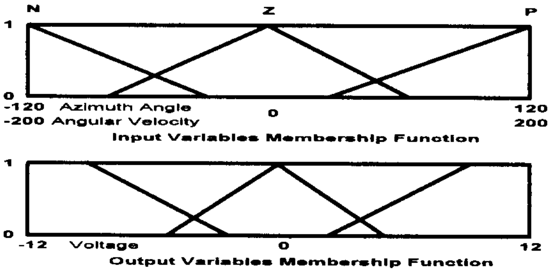
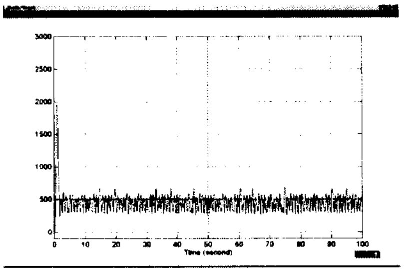


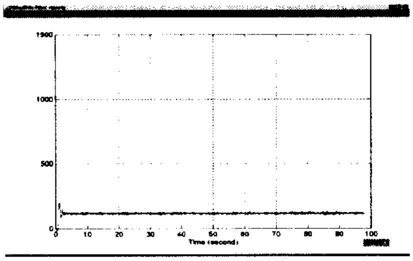
Fig.8. Membership Function for Azimuth Angle

4. results of simulation and discussion

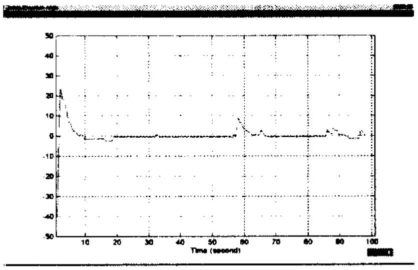
The simulation results of the PID controller and the fuzzy one are shown in Fig.9 and Fig.10, respectively. The initial value was 0[Deg] for the vertical angle and 180[Deg] for the azimuth one. The performances of the fuzzy controller in Fig.10 were superior to those of the PID controller.



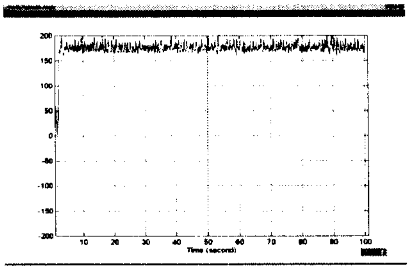
(a) Angular Velocity of Main Rotor



(b) Angular Velocity of Side Rotor

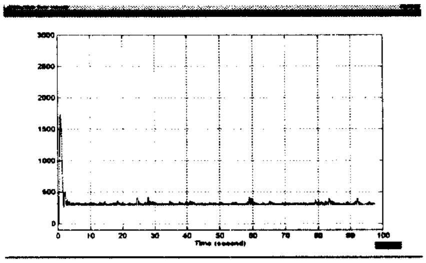


(c) Elevation Angle

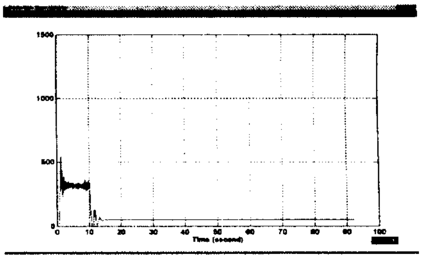


(d) Azimuth Angle

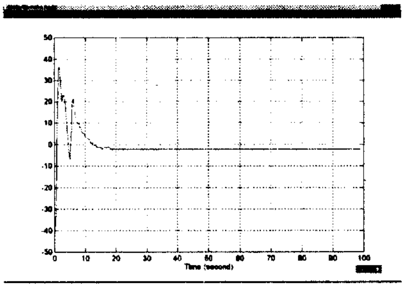
Fig.9. Results of PID Controller



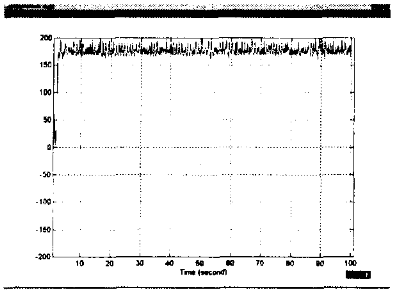
(a) Angular Velocity of Main Rotor



(b) Angular Velocity of Side Rotor



(c) Elevation Angle



(d) Azimuth Angle

Fig.10. Results of Fuzzy Controller

5. conclusion

In this paper, a fuzzy control method for the attitude control of a helicopter known as the unstable nonlinear plant is introduced and the performances of the controller were evaluated via simulations. By adding the algorithm which generate the optimal rules of the fuzzy controller, the performances of the fuzzy controller showed better results than those of the PID one.

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