Adaptive Fuzzy Controller Design for Altitude Control of an Unmanned Helicopter

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Abstract: Unmanned Helicopter has several abilities such as vertical Take off, hovering, low speed flight at low altitude. Such vehicles are becoming popular in actual applications such as search and rescue, aerial reconnaissance and surveillance. These vehicles also used under risky environments without threatening the life of a pilot. Since a small unmanned helicopter is very sensitive to environmental conditions, it is generally known that the flight control is very difficult problems.

The nonlinear adaptive fuzzy controller design procedure and its applications for altitude control of unmanned helicopter were described in the paper. This research was concentrated on describing the design methodologies of altitude controller design for small unmanned helicopter acquiring autonomous take off and vertical movement. The design methodologies and performance of the altitude controller were simulated and verified with an adaptive fuzzy controller. Throughout simulation results, I showed that the proposed adaptive controllers have enhanced control performance such as robustness, effectiveness and safety, in the altitude control of the unmanned helicopter.

Keywords: Flight Controller, Unmanned Helicopter, Altitude Control, Fuzzy Control, Adaptive Fuzzy Control

1. Introduction

The unmanned aerial vehicles (UAV) are remotely piloted or self-piloted aircraft. Recently, their abilities are much more that they carry cameras, sensors, communications equipment, or other payloads. Some day several UAV are operated in military purposes such as reconnaissance, surveillance, and intelligence of enemy forces without risking the lives of an aircrew. These actual applications need more versatile performance. Among these abilities hovering and vertical take off ability are necessarily needed. The helicopter can flight by resulting lifting force of large radius main rotor. For the single rotor helicopter, it use tail rotor to prevent body rotation. Thus the two state variables, azimuth angle and elevation angle, are strongly coupled, and have characteristics of typical MIMO system. The hovering capability of small helicopters can potentially be used in actual application. It is necessary to design a feedback control system with adequate closed loop bandwidth. This paper was concentrated on describing the altitude control dynamics, adaptive fuzzy controller and their interconnections for acquiring autonomous altitude control. The equations of motion were derived by the general Newton-Equation for a rigid body. The design methodologies and performance of the helicopter were illustrated and verified with a upward equation of motion and adaptive fuzzy control rules. The direct adaptive controller based fuzzy controller and nonlinear fuzzy control rule was designed and tested for this unmanned helicopter.

2. Modeling of the Unmanned Helicopter

4.2.2.1. Altitude Control of Unmanned Helicopter

Unmanned Helicopter has several abilities such as vertical Take off, hovering, low speed flight at low altitude. Such vehicles are becoming popular in actual applications such as search and rescue, aerial reconnaissance and surveillance. These vehicles also used under risky environments without threatening the life of a pilot. In this paper, the adaptive fuzzy controller design method for the altitude control of an unmanned helicopter was derived. Through simulation results, we show that the proposed adaptive controllers have enhanced control performance such as robustness, effectiveness and safety, in the altitude control of the unmanned helicopter.

Modeling of Vertical Motion

The pitch of main rotor and the output of engine are much important in helicopter vertical motion. The force acting on an unmanned helicopter during vertical movement is shown in figure 1.

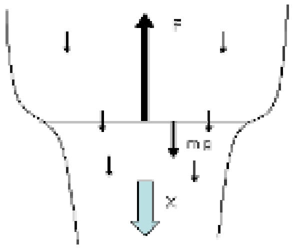

Fig. 1. Force Acting on an Unmanned Helicopter during Vertical Movement

where, F is total vertical upward forces (lift plus thrust) and X is drag force acting on vertical direction. This force equation is can be expressed by following equation 1.

$$ma = F + sign(-v)|x| - G \tag{1}$$

where, *m*, *a*, *v*, and *G* are mass, acceleration, velocity and weight of unmanned helicopter. Relational equations between lift and drag force are can be given by following equation 2 and 3.

$$F = f(\Xi) K_{gt} G \tag{2}$$

$$X = sign(-v) \frac{C_l S \Upsilon}{2} v^2 \tag{3}$$

where, $f(\Xi)$ is relational equation between pitch angle of main rotor and lift force. In this research, this equation is derived by experiment and the resultant equation is shown in equation 4.

$$f(\Xi) = sign(\Xi) \times 8.1 \times 10^{-4} \times \Xi^2 \tag{4}$$

where, Ξ is pitch angle of main rotor, K_Ξ is mass margin, is lift coefficient of main rotor blade, is cross sectional area of main rotor blade and is air density.

Final altitude equations are derived by following equation 5, 6 and 7.

$$\dot{v} = \frac{X + F - G}{m} \tag{5}$$

$$\dot{H} = v \tag{6}$$

$$\Xi = K_\Xi (u - \dot{v}) \tag{7}$$

where, H, and are altitude, K_Ξ is control gain value and u control input(target acceleration). The nonlinear altitude dynamics of unmanned helicopter are shown in the following equation 8~12.

$$v_{t+1} = \frac{F_t + X_t - G}{m} \nabla t + v_t \tag{8}$$

$$H_{t+1} = v_t \nabla t + H_t \tag{9}$$

$$F_t = f(\Xi) K_{gt} G \tag{10}$$

$$X_t = sign(-v_t) \frac{C_l S \Upsilon}{2} v_t^2 \tag{11}$$

$$\Xi_{t+1} = K_\Xi \left(u - \frac{v_t - v_{t-1}}{\nabla t}\right) + \Xi_t \tag{12}$$

where, the parameters of designed industrial radio controlled unmanned helicopter were used for these simulations.

3. System Design of the Unmanned Helicopter

3.1. Structural Design

AutoCAD-2000 and CATIA-V6 were used for this structural Design. And the system parameters were also derived by using these computer tools. The test helicopter has four blades teetering rotor augmented with direct head system. Figure 2 represents that the overall 2-D structure design of the unmanned Helicopter. Rotor speed range is 750-820 RPM. Two electronic governors maintain commanded rotor speed by adjusting throttle commands. Figure 3 represents the 3-D Design of the whole unmanned helicopter.

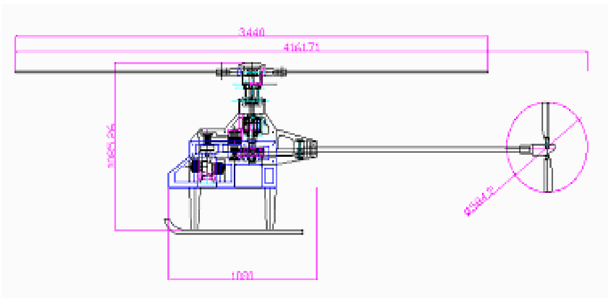

Fig. 2. 2-D Design of Unmanned Helicopter

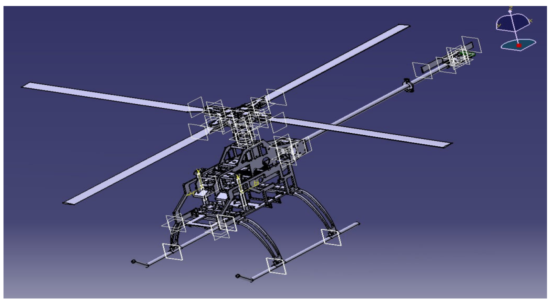

Fig. 3. 3-D Design of Unmanned Helicopter

3.2. Aerodynamic Design

To calculate the thrust of main rotor, the non-steady uniform strength source-doublet panel method was used. By using this panel method, downstream and thrust was calculated. To illustrate distortions of the downstream, vortex lattice method was used for the calculation of downstream rollup. Vortex core model of Scully was also used to eliminate the singularity on the center of vortex. Also, to eliminate potential value of downstream panel which collided with blade, solid boundary condition would be satisfied when downstream panel was in wing. Figure 4 illustrate upper view of the main rotor blade, pressure distribution and wake shape at collective angle is 12°. Following figure 5 illustrates calculate thrust curve with respect to collective angles. About 100kgf of rotor thrust was produced at collective angle 8°. In spite of considering computational error, the calculation result was sufficient for the unmanned helicopter thrust. With increasing the collective angle, the more thrust can be acquired.

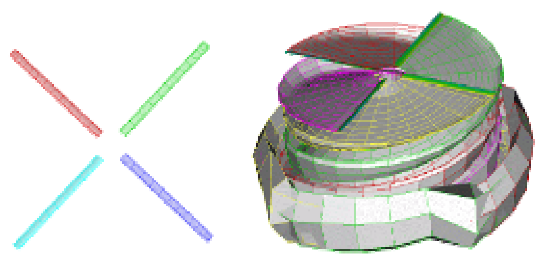

Fig. 4. Main Rotor Blade and Pressure Distribution and wake

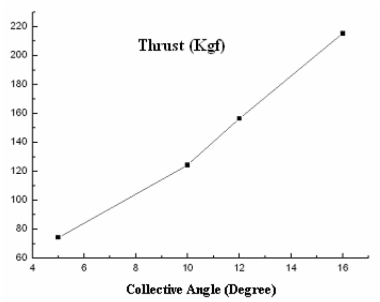

Fig. 5. Thrust Curve with respect to Collective Angles

3.2. Attitude Controller Design

The reference model was selected as 2nd order stable system and input/output membership functions are chosen as exponential functions shown in figure 6. The results of altitude control are given by following Figure 7~8. In figure 7, change of altitude and velocity on rising is represented with time when target reference model having 150 second settling time. As shown in this figure, the results are stable and the controlled helicopter altitude smoothly follows the reference model behavior trajectory. As shortening the settling time, the reference model also converges more rapidly. Figure 8. shows the changes of altitude of an unmanned helicopter during the rise at different reference model. By the 20 second of settling time, the adaptive altitude control system well follow the reference model trajectory. This figure shows the stages during the rise of an unmanned helicopter at different reference altitude. From 5m to 20m of reference altitude variation, the adaptive controller pursuit the reference model trajectory excellently. If poor result is occur in some case, the result can be convergent. Consequently, in these simulations, it is proved that the adaptive fuzzy controller is a excellent design method for the altitude control of unmanned helicopter. Figure 9. shows the values of adaptation parameter theta.

4. Conclusions and Further Research

Computer based design and simulation for altitude control of the unmanned helicopter was performed. System design, controller design, configuration design and interference were also tested for the designed unmanned helicopter. And an altitude controller was simulated for the designed unmanned helicopter. A multivariable controller was designed, tested and verified with computer simulation. From this study, it is verified that designed adaptive Fuzzy controller is reasonable controller for the altitude control of the unmanned helicopter. Next step on the way to autonomous helicopter is to create a well designed test procedure, GCMS(Ground Control and Monitoring System) and a linearized wide-areas model, adequate for control law design. And the nonlinear model will be used in the hardware-in-the-loop simulation to check out control software. The state estimation method such as Kalman filter is required for robust to short GPS outages. Also, it is required that the RTOS(Real Time Operating System) is implemented to autopilot computer for graphical interface and it is necessary that the communication with the ground station via a wireless system. It will give more convenient environments to further research. The state estimation method such as Kalman filter is required for robust to short GPS outages.

Acknowledgement

This research was supported by the Program for the Training of Graduate Students in Regional Innovation which was conducted by the Ministry of Commerce, Industry and Energy of the Korean Government.

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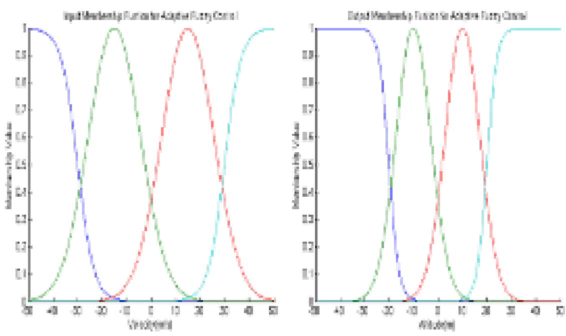
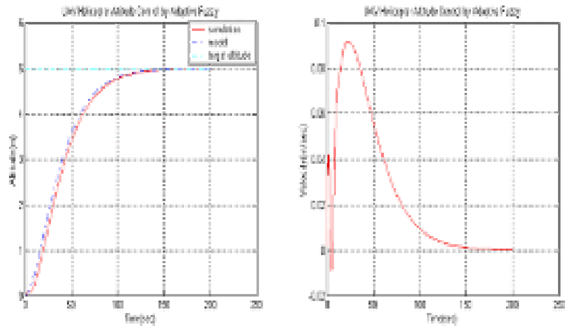


(a) Input(Velocity) (b) Output(Altitude)

Fig. 6. Exponential Input and Output Membership Functions



(a)Altitude (b) Velocity

Fig. 7. Change of Altitude and Velocity

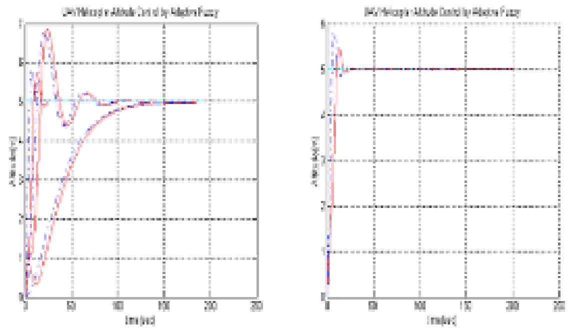


Fig. 8. Attitude Responses at Different Reference Model

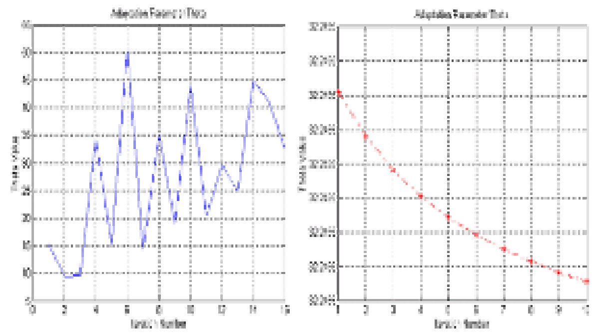


Figure 9. Values of Adaptation Parameter Theta