FUZZY-PID ALGORITHM CONTROL FOR HELI2DOF

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ABSTRACT

Heli2DOF model is designed in the laboratory for studying of basic problem in the helicopter control. Due to its mechanical structure, the helicopter has itself created the unwanted moments while operating that effect to the flight. The movement in center of gravity will cause disturbance torques in flight, which makes the helicopter dive downward/ upward or negative change in the altitude. This is because the body of the helicopter is similar to a pendulum hanging from the main rotor; any changes of center of gravity (CG) definitely cause changes in this angle and disturbance. This issue should be controlled by the automatic controller in order to reduce the burden on the flight operator. This paper presents the idea of the Algorithms of PID combined with Fuzzy that solve this issue, also it is stability assistance of the system, even there is the disturbance of aircraft gravity. The authors suggest Fuzzy logic controller in order to adjust the PID coefficients for the purpose of its efficiency with the nonlinearity of the system in the Pitch (**θ**) and Yaw (**ψ**) angle position control. Under the disturbance wind causing the loss of control of aerodynamics force of the propeller, nonlinearity of the system is very high; however, the controller ensures the control of system. This idea has been successfully on this Heli2DOF model.

Keywords: Helicopter 2DOF, nonlinear MIMO system, Automatic Control Helicopter 2DOF, Fuzzy-PID control for Heli2DOF.

INTRODUCTION

One of the factors that affects the quality of helicopter's flying is the change of gravity which results in unstable altitude of helicopter in space; for instance, the turbulence in the fuel or cooling water tank, movements of the passengers during flight, or external factors such as wind, sudden loading change, etc. The movement in center of gravity will cause disturbance torques in flight, which makes the helicopter dive downward/upward or negative change in the altitude. This is because the body of the helicopter is similar to a pendulum hanging from the main rotor; any changes of center of gravity (CG) definitely cause changes in this angle and disturbance. The details of CG's effects on the flight performance are illustrated in [1], [2]. The pilots have to work harder to control the stability. Otherwise, this situation can be governed by an automatic control system. However, the nature of this disturbance is hard to be accurately modeled in math equations; it is, therefore, necessary to construct nonlinear controllers based on the uncertain input data.

Heli2DOF model is a simple kinematics structure of a helicopter with two degree of freedom. In the real flight, aerodynamic force from the rotor is adjusted by the change of blade angle in the fixed speed of rotor. In order to simplify the model's mechanical structure, Heli2DOF has propellers with fixed blade angle and the force is changed by the change of the propeller speed. This makes Heli2DOF turn into a complicated nonlinear system. Torques caused by the change of propeller speed will add into the disturbance torques.

The problem has been solved by various algorithms. 2-Sliding Mode Based Robust Control for 2-DOF Helicopter was illustrated in [3]; in [4], Piecewise-Linear Neural Model focused on Helicopter Elevation Control; Adaptive algorithm applied in [5] used Attitude Observer-Based Robust Control. The mentioned strategies show feasibility by experiments on Heli2DOF. In the real flight condition, helicopter is affected by various external disturbance factors which negatively impact flight quality such as wind, air pressure, temperature, humidity, etc. In laboratory, impact of wind (low frequency) <3Hz and change of load were performed on Heli2DOF.

Advantages of PID controller such as reliability, simplicity, low volume of calculation, being easily performed in the microcontrollers by programing languages make this controller preferred in the controlling industry. Fuzzy logic controller has advantages which are the flexibility, non-necessity of deep knowledge regarding math models of the subjects; it is constructed based on the system observation and experience of the programmers.

LITERATURE REVIEW

In this research [7], there are investigations both modelling and experimental identification of similar 2-DOF helicopters, see Ahmad et al. (2000b); Rahideh and Shaheed (2007); Ahmad et al. (2000a); Darus et al. (2004); Shaheed (2004). The methods proposed therein correspond to typical experimental set-ups from different manufacturers, various model-based approaches and methods employing artificial intelligence, e.g., radial basis functions, neural networks and genetic algorithms. In Rahideh and Shaheed (2007), a complete mathematical description of a 2-DOF helicopter using different approaches is described. A simulation study of a nonlinear predictive control is presented for a ninth-order model in Dutka et al. (2003). In Lopez-Martinez et al. (2004), a feedback-linearising control scheme is proposed for the pitch motion only. Therein, the yaw angle is not considered as a DOF. An H_∞ controller for helicopter dynamics is described in Lopez-Martinez et al. (2003, 2005). The resulting controller exhibits the attributes of a nonlinear PID with time-varying constants according to the operating point. In Ahmed et al. (2009), a sliding mode control dealing with the couplings of a helicopter with two rotors is considered. An adaptive second order sliding mode control has been proposed in Mondal and Mahanta (2012); however, no experimental validation is presented therein. In this paper, The authors suggest Fuzzy logic controller in order to adjust the PID coefficients for the purpose of its efficiency with the nonlinearity of the system in the Pitch ($\boldsymbol{\theta}$) and Yaw ($\boldsymbol{\psi}$) angle position control.

METHODOLOGY

System Description

Physical structure of Heli2DOF is illustrated in (Figure 1) [3]. It is a twin rotor aero dynamic system: main rotor and tail rotor. The rotary axis of the main rotor is perpendicular to the Pitch axis and the rotary axis of tail rotor is parallel to the Pitch axis. The whole system is linked with the shelf by two couplings.

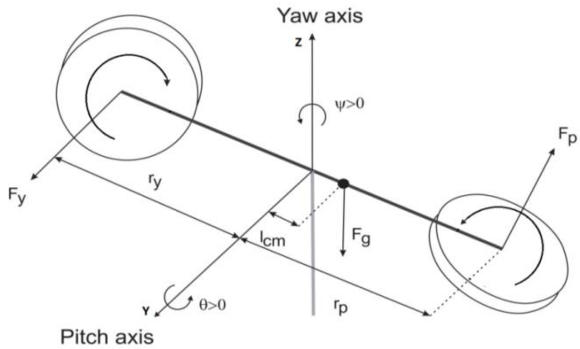


Figure 1. Heli2DOF model

Basic parameters of Heli2DOF:

m_{heli}: Total moving mass of helicopter (body, two propellers assemblies, etc.);
m_{Heli_θ}: Mass moving about Pitch axis;
l: Center of mass length along helicopter body from Pitch axis;
l_{θ}: Center of mass length along helicopter body from Pitch axis about Pitch axis;
J_{θ}: Moment of inertia of helicopter body about Pitch axis;
J_{ψ}: Moment of inertia of helicopter body about Yaw axis;
J_{eq_p}: Total moment of inertia about Pitch axis;
J_{eq_y}: Total moment of inertia about Yaw axis;
F_p: Force of aerodynamics from main rotor;
F_y: Force of aerodynamics from tail rotor;
ω_p: Angular velocity of main rotor;
ω_y: Angular velocity of tail rotor;
u_p: Signal controlling main rotor's speed;
u_y: Signal controlling tail rotor's speed;
M_{y_θ}: Moment of the tail rotor affecting Pitch axis;
M_{y_ψ}: Moment of the tail rotor affecting Yaw axis;
M_{p_θ}: Moment of the main rotor affecting Pitch axis;
M_{p_ψ}: Moment of the main rotor affecting Yaw axis;
B_{θ}: Equivalent viscous damping about Pitch axis;
B_{ψ}: Equivalent viscous damping about Yaw axis;
K_{pp}: Thrust torque constant of Pitch axis/ Signal controlling main rotor's speed; $\theta>0$ $\psi>0$
K_{py}: Thrust torque constant of Pitch axis/ Signal controlling tail rotor's speed;
K_{yp}: Thrust torque constant of Yaw axis/ Signal controlling main rotor's speed;
K_{yy}: Thrust torque constant of Yaw axis/ Signal controlling tail rotor's speed;

According to [6], differential equations describing the system are illustrated as follows:

$$\ddot{\theta} = \frac{1}{J_{eq\_p}+m_{heli}.l^2}.\left[k_{pp}.u_p - m_{heli_{\theta}}.g.l_{\theta}.sin\theta + k_{py}.u_y - B_{\theta}.\dot{\theta}\right] \text{ (*)}$$

$$\ddot{\psi} = \frac{1}{J_{eq\_y}+m_{heli}.l^2}.\left[k_{yy}.u_y.sin\theta - k_{yp}.u_p.sin\theta - B_{\psi}.\dot{\psi}\right] \text{ (**)}$$

$$M_{y\_\psi} = u_y * K_{yy}$$

$$M_{p\_\theta} = u_p * K_{pp}$$

$$M_{y\_\theta} = u_y * K_{py}$$

$$M_{p\_\psi} = u_p * K_{yp}$$

Investigation of Heli2DOF Simulation

The system is illustrated under transfer function from *(*) and (**)*, the system is constructed by block diagram in Matlab Simulink illustrating Heli2DOF (*Figure 2*). Inputs are $\boldsymbol{u_p}$ and $\boldsymbol{u_y}$; ouputs are response of angle position $\boldsymbol{\theta}$, $\boldsymbol{\psi}$ and corresponding angle velocity. Kinetic parameters are in the *Table 1*.

Table 1. Kinetic parameters of the model simulation

Parameter	Value	Unit
m_{heli}	1.02	*kg*
m_{Heli_θ}	0.6	*kg*
l	0.09	*m*
l_θ	0.17	*m*
rp	0.206	*m*
ry	0.2	*m*
J_{eq_p}	0.0432	$kg.m^2$
J_{eq_y}	0.0384	$kg.m^2$
B_θ	0.812	*N/v*
B_ψ	0.75	*N/v*
K_{pp}	0.412	*N.m/V*
K_{py}	0.0068	*N.m/V*
K_{yp}	0.0219	*N.m/V*
K_{yy}	0.26	*N.m/V*

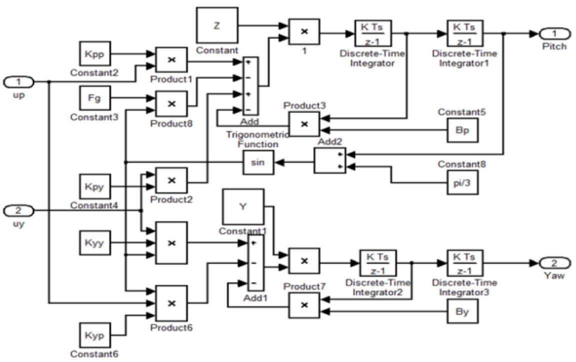


Figure 2. Heli2DOF constructed on Matlab Simulink

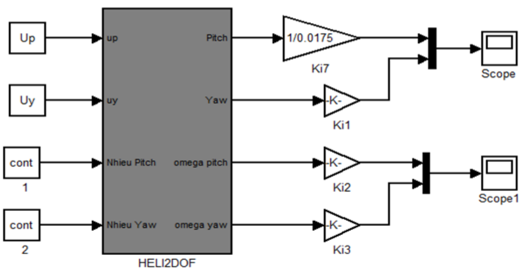


Figure 3. Simulation display

Investigation with u_p= 0.5v; u_y= 0v

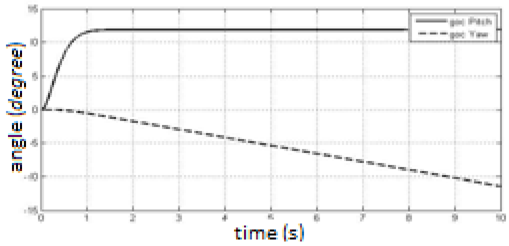


Figure 4. Response of angle position $\boldsymbol{\theta}$, $\boldsymbol{\psi}$

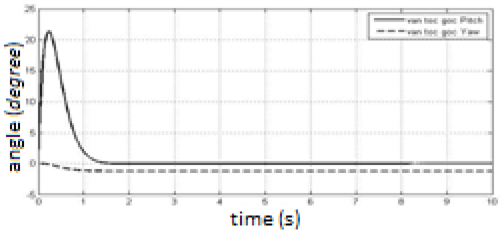


Figure 5. Response of angular velocity $\boldsymbol{\omega_\theta}$, $\boldsymbol{\omega_\psi}$

Investigation with u_p= 0 v; u_y= 0.2 v.

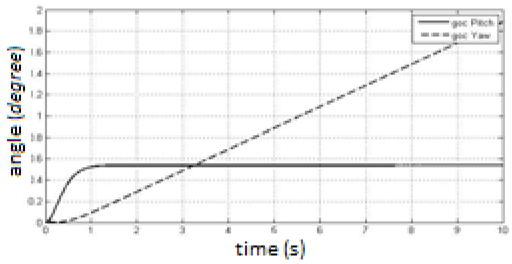


Figure 6. Response of angle position $\boldsymbol{\theta}$, $\boldsymbol{\psi}$

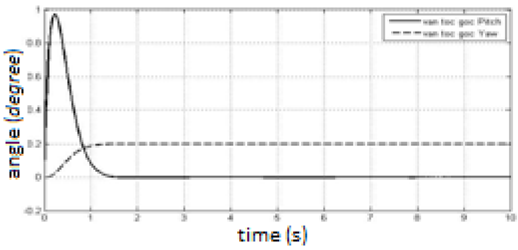


Figure 7. Response of angular velocity $\boldsymbol{\omega_\theta}$, $\boldsymbol{\omega_\psi}$

Investigation with u_p= 1,2v; u_y= 0,333v

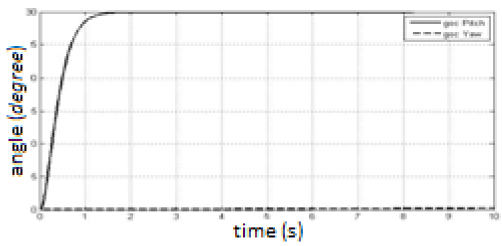


Figure 8. Response of angle position $\boldsymbol{\theta}$, $\boldsymbol{\psi}$

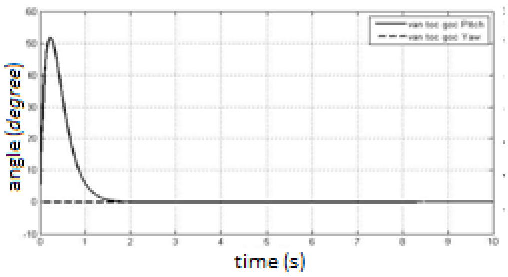


Figure 9. Response of angular velocity $\boldsymbol{\omega_\theta}$, $\boldsymbol{\omega_\psi}$

Investigation with u_p= 1,2v; u_y= 0,333v, Disturbance Load at the 5^{th} second.

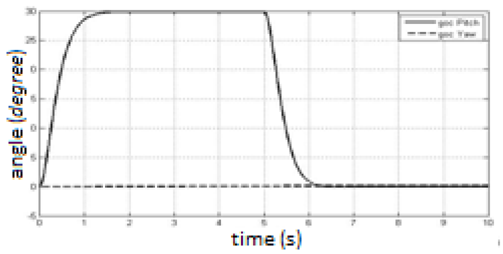


Figure 10. Response of angle position $\boldsymbol{\theta}$, $\boldsymbol{\psi}$

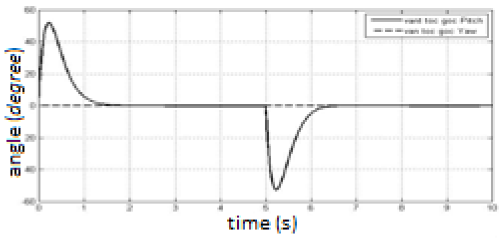


Figure 11. Response of angular velocity $\boldsymbol{\omega_\theta}$, $\boldsymbol{\omega_\psi}$

RESULTS

Simulation of PID Controller for Heli2DOF System

Heli2DOF is MIMO system with 2 inputs: $\boldsymbol{u_p}$ and $\boldsymbol{u_y}$; 2 outputs: angle position of Pitch and Yaw; in order to simplify the controlling structure, the system is considered as 2 independent SISO systems and $\boldsymbol{M_{\psi p}}$,$\boldsymbol{M_{\theta y}}$ are disturbance caused by itself on the system but can absolutely be measured by examination to calculate $\boldsymbol{K_{py}}$ – constructing controller to stabilize angle Pitch then gradually increase $\boldsymbol{u_y}$ till $\boldsymbol{M_{y\_\psi}}$ is approximately equal to $\boldsymbol{M_{\psi p}}$; it is the same to calculate $\boldsymbol{K_{yp}}$. For the purpose of reduce the amplitude of disturbance, the solution is as follows:

$\boldsymbol{u_p} = \boldsymbol{u_{px} - K_{py}.\, u_y}$

$\boldsymbol{u_y} = \boldsymbol{u_{yx} + K_{yp}.\, u_p}$

($\boldsymbol{u_{px}}$ and $\boldsymbol{u_{yx}}$ are signals following 2 controllers)

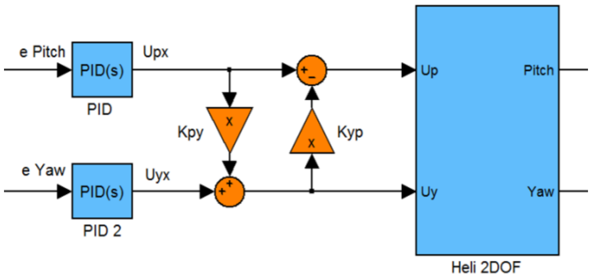


Figure 12. Controlling structure

Simulation Result

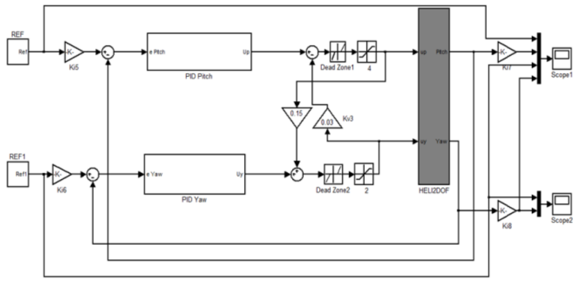


Figure 13. PID Controller Heli2DOF system

Setpoint Pitch = 30 degree, Yaw = 0 degree

The coefficients of PID controller are optimized by Ziegler – Nichols method with a number of real conditions:

Deadzone $\boldsymbol{u_p}$ from 0 to 1 *(v).*
Saturation $\boldsymbol{u_p}$ from 0 to 5 *(v).*
Deadzone $\boldsymbol{u_y}$ from 0 to 0.8 *(v).*
Saturation $\boldsymbol{u_y}$ from 0 to 5 *(v).*

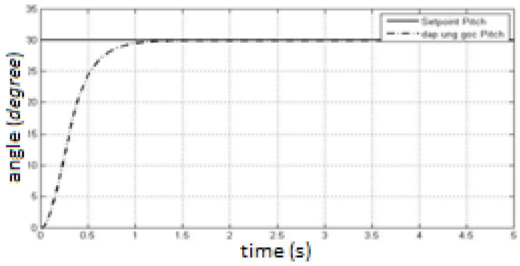


Figure 14. Response of angle $\boldsymbol{\theta}$ (Kp=15,Ki=4.5,Kd=2)

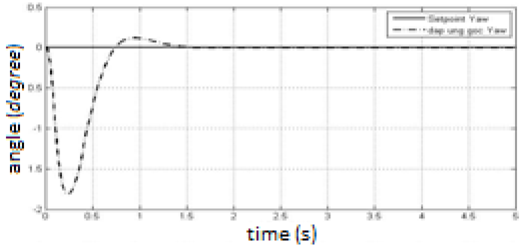


Figure 15. Response of angle $\boldsymbol{\psi}$ (Kp=8,Ki=2,Kd=4)

Response at Different Setpoint

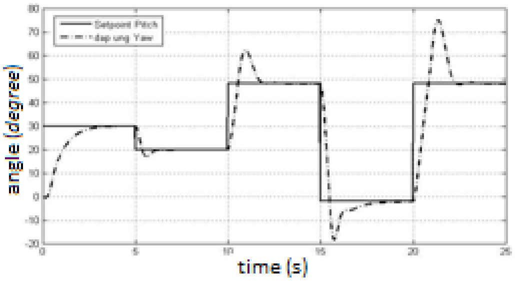


Figure 16. Response of angle $\boldsymbol{\theta}$ setpoint = 30, 20, 50, 0, 50 degree.

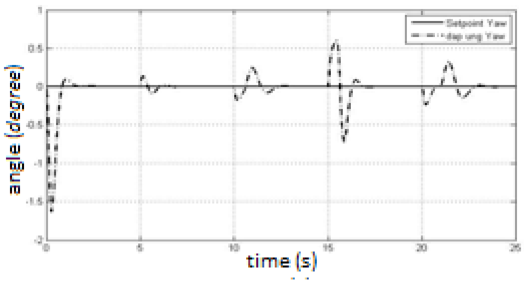


Figure 17. Response of angle $\boldsymbol{\psi}$ setpoint = 0 degree

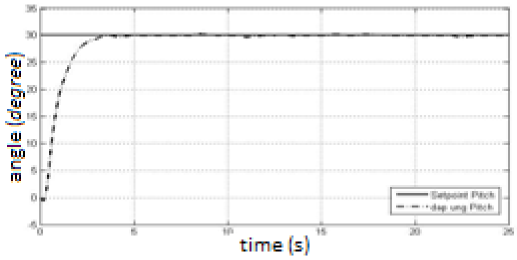


Figure 18. Response of angle $\boldsymbol{\theta}$ setpoint = 30 degree

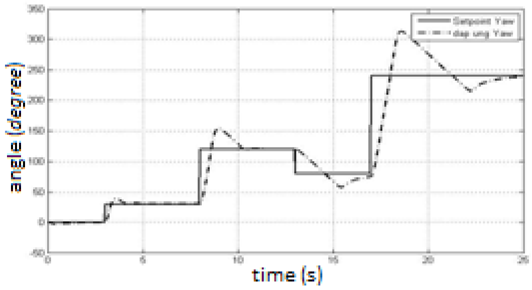


Figure 19. Response of angle $\boldsymbol{\psi}$ = 30, 120, 80, 240 degree

Constructing Fuzzy-PI&D Controller for Heli2DOF

The objective of Fuzzy Controller is to adjust P, I and D coefficients to match with different linear areas of the system. The idea is constructed as following:

Model structure has Moment $(F_g.l_\theta.\sin\theta)$. It is nonlinear and plays a role of loading. u_p Signal is linear generated by PID Controller, which is, therefore, unsuitable with loading attribute and generates big overshooting at different setpoints. It is, therefore, necessary to linearize nonlinear different loads into linear areas; each area uses different PID Controllers with appropriate coefficients. There is also a need to take e error of Pitch angle into account.

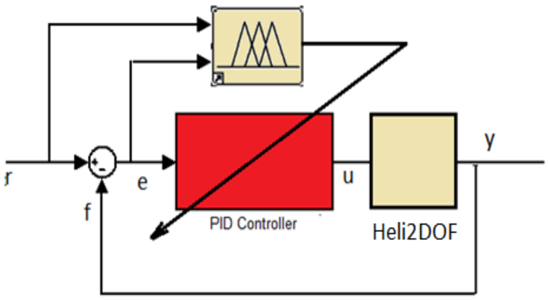


Figure 20. System controller structure

Set up Fuzzy Toolbox

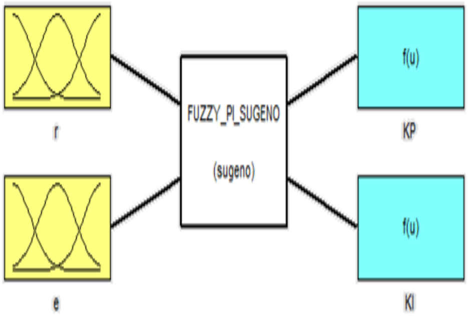


Figure 21. Structure of Fuzzy system

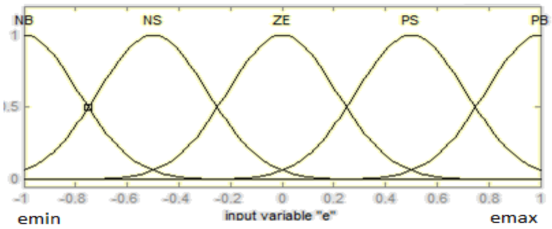


Figure 22. Membership function of e input

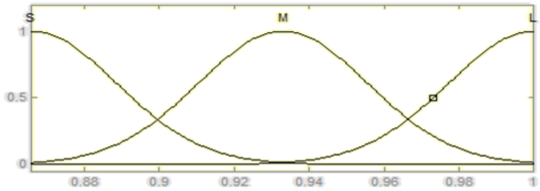


Figure 23. Membership function of r input

Areas of Input Variables of Fuzzy Logic Controller Are Determined as Follows:

$$e \in [e_{min}, e_{max}] \quad \rightarrow \quad e \in [-1,1]$$
$$r \in [\sin 60^o, \sin 90^o] \rightarrow y \in [0.867,1]$$

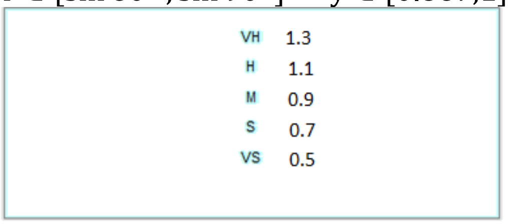


Figure 24. Membership function of Kp output

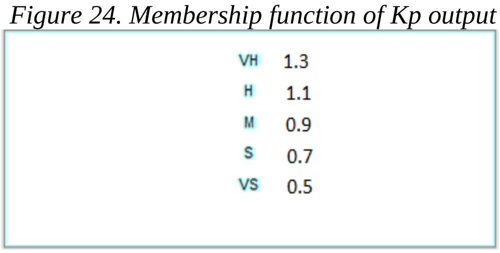


Figure 25. Membership function of Ki output

{Kp,Ki} of Fuzzy logic controller is determined around values $\{K_{P\_ZN}, K_{I\_ZN}\}$ which are obtained from Zigler-Nichols method, with α=0.5 and β=1.3

$$\alpha K_{P\_ZN} < K_P < \beta K_{P\_ZN}$$
$$\alpha K_{I\_ZN} < K_I < \beta K_{I\_ZN}$$

The Rule Has Been Developed

If r is large, Kp is large and Ki is large; if r is small, Kp is small and Ki is small…
If e is large, Kp is large and Ki is large; if e is small, Kp is small and Ki is small…

Table 2. The rules

Kp/Ki		**r**		
		S	**M**	**L**
e	**NB**	M/M	H/H	VH/VH
	NS	S/S	M/M	H/H
	ZE	VS/VS	S/S	M/M
	LS	S/S	M/M	H/H
	LB	M/M	H/H	VH/VH

Simulation Results

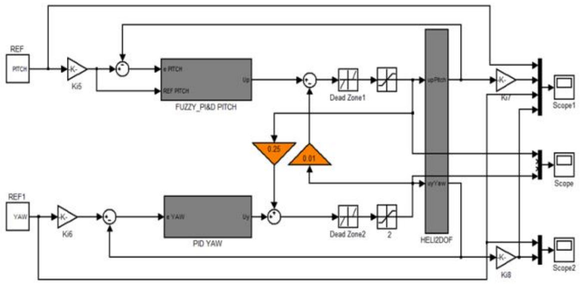


Figure 26. Fuzzy-PI&D Controller for Pitch angle of Heli2DOF

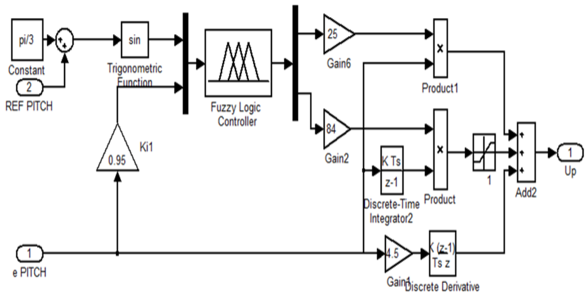


Figure 27. Structure of Fuzzy-PI&D Controller for Pitch angle

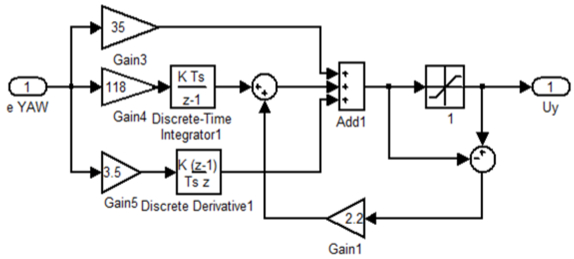


Figure 28. Structure of windup for PID Controller of Yaw angle

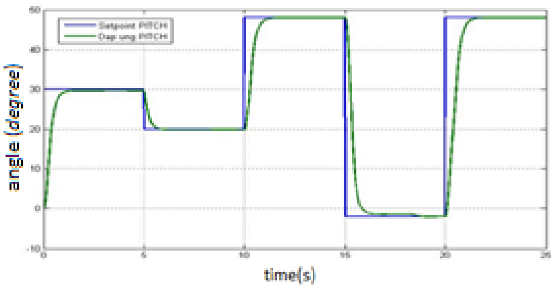


Figure 29. Response of Pitch angle

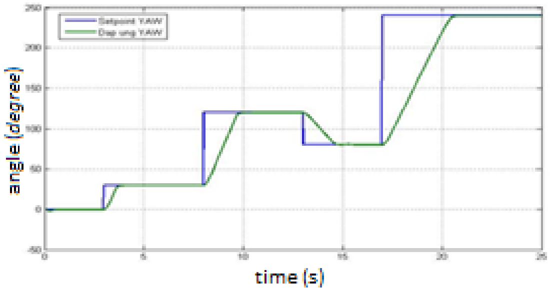


Figure 30. Response of Yaw angle

Controller Implementation

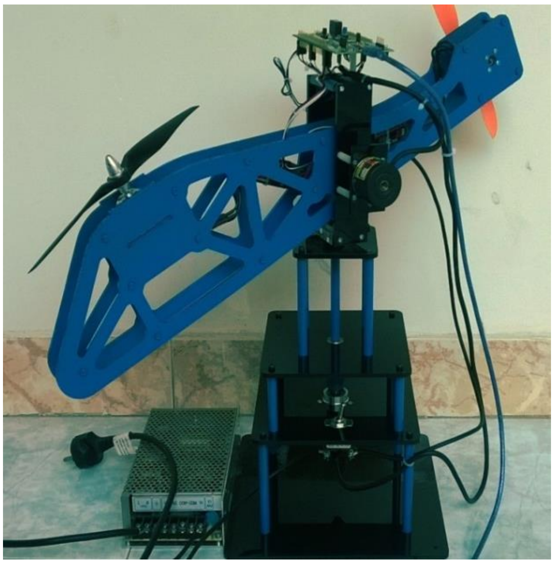


Figure 31. Real Heli2DOF

Electrical System and Controller

Kit STM32F4 reads setpoint signal from computer and feedback signal of Pitch angle position and Yaw's from encoder, calculates outputs based on algorithm and exports signals controlling 2 motor's speed via ESC driver. System's response is observed on the computer via the communication port; the system's sampling frequency is 50Hz.

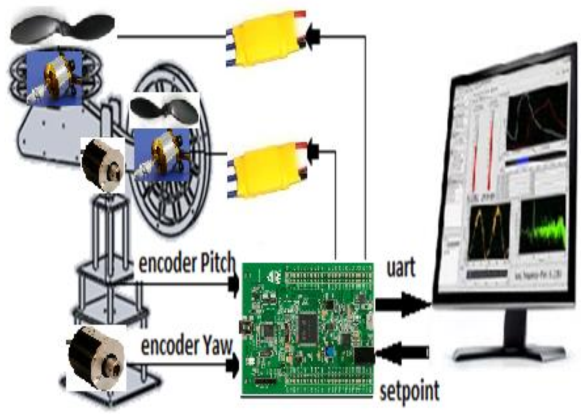
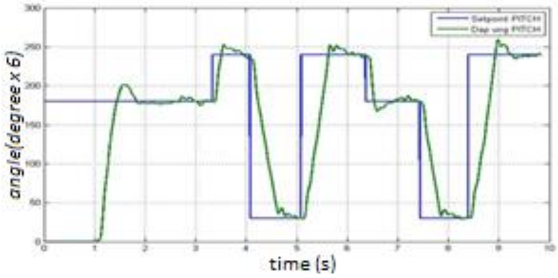


Figure 32. Structure of Control system and observation

System's Response with Setpoints



Hình 33. Response of Pitch of Fuzzy-PI&D Controller

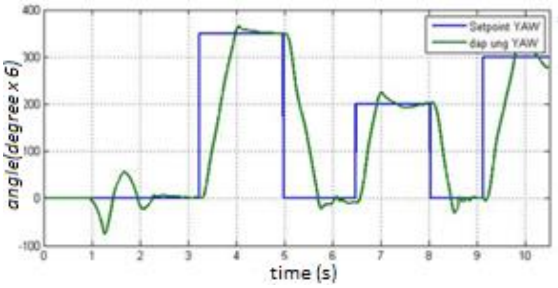


Figure 34. Response of Yaw of PID-windup Controller

Response with Loading Disturbance of 350g (60%) at the 4th Second

- Setpoint Pitch =180 equivalent 30^o
- Setpoint Yaw = 0.

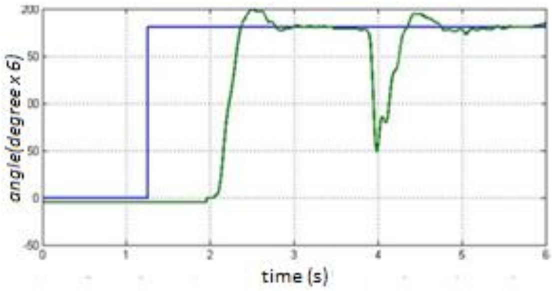


Figure 35. Response of Pitch

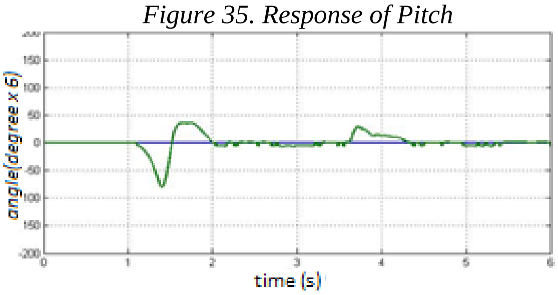


Figure 36. Response of Yaw

Response with Wind Across Helicopter Body, Unstable Frequency<3Hz, Speed ~60km/H, Magnitude ~ 8N.

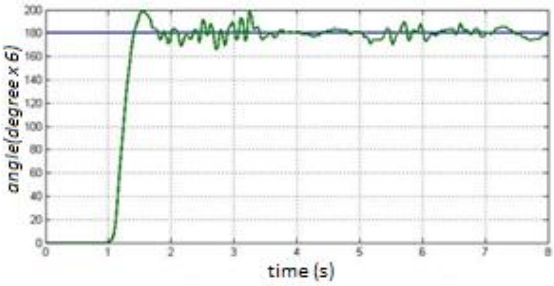


Figure 37. Response of Pitch with wind across helicopter body

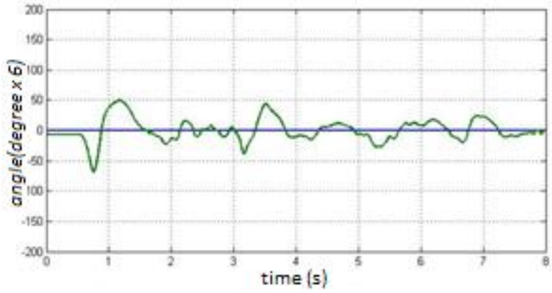


Figure 38. Response of Yaw with wind across helicopter body

DISCUSSION

Examination result of controlling signals $\boldsymbol{u_p}$ and $\boldsymbol{u_y}$ from 0 to 5(v) in 10s is the effect of the main rotor's momentum torque to Yaw axis (1) and the tail rotor's momentum torque to Pitch axis (2); (2) has much lower intensity than (1). In real helicopter with small tail rotor and long $\boldsymbol{r_y}$, (2) is minor but is still balanced with (1).

Heli2DOF system can be stable with open-loop controller when thrust force of main rotor is equal to total of gravity about Pitch axis and (2); thrust force of tail rotor is equal to (1). However, under the effect of disturbance, the system totally loses its control, it is, therefore, necessary to construct close-loop controller to ensure the system stability.

Heli2DOF is a high non-linear system because load moment is a sin function ($\mathrm{F_g}.\mathrm{l_\theta}.\sin\theta$) [6] and non-linear attribute of aerodynamics force from propeller. Linear PID controller can work relatively effectively at one working point where the coefficients are difficultly searched. In order to obtain high quality control, it is necessary to investigate nonlinear controllers.

Fuzzy PI&D Controller in the simulation has solved the disadvantages of PID Controller for Pitch, eliminated overshooting. Regarding Yaw, by using windup for PID, the overshooting has been eliminated *(Figure 29 & 30).*

Under the condition of relatively strong wind, wind force directly attacks helicopter body; high speed wind affects aerodynamics force of propeller. The system deviates out of the balanced position especially the Yaw; however, everything is still under the control. When disturbance magnitude is stable, the system is quickly back to the balanced position.

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CONCLUSIONS

The paper has presented strategies constructing Fuzzy-PI&D Controller for Pitch and Yaw position of Heli2DOF which can solve the nonlinearity of the system.

Under the disturbance wind causing the loss of control of aerodynamics force of the propeller, nonlinearity of the system is very high; however, the controller ensures the control of system. When the disturbance load is equal 50% of system gravity, the system quickly gets back to the balanced position but the error magnitude is still high.

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