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Modelling and Control of 3-DOF Helicopter

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Abstract: The objective of this paper is to evolution of a mathematical modeling for and control of helicopter three degree of freedom. And these mathematical modeling is done using the free body diagram. The PID controller is designed. For designing of PID, skogestad tuning method was used. The results are clearly shows that the controller performs good for all the three axis such as pitch, elevation and roll axis. And also the results shows that it can control system like with working characteristics in spite of non linear systems.
Keywords: Mathematical modelling, control, PID, skogestad, 3-dof helicopter.

I. INTRODUCTION

The helicopter with three degree of freedom consist of a long pivoted and which is fixed on a vertical bars, two motors are fixed at the end of the arm which has variations in voltage and also which create thrust force at the opposite end the counterweight is provided and this is provided in order to control the angle of elevations such as pitch and travel.

The model based control approach to be contingent on the mathematical representation of the system. Usually the helicopter considerably highly non-linear, as the complication of the system potential to complete and model of the system becomes very difficult. In order to stabilize this nonlinear system many control strategies have been involved. In [1] using LQR (Linear-Quadratic-Regulator) technique controller is planned. In [2]to control the travel angle cascade controller is designed. In[3] controller is designed for a fuzzy controller that control travel angle and elevation of the helicopter.

A robust control was designed for the small helicopters such[4] that and also in order to track attitude in some mission. In some cases the flexible neural Tolerant control scheme is considered in subject with uncertainties, external disturbances and also actuator faults[5]. All the unmanned helicopter are highly non-linear and also Multiple-input and multiple-output system with subjected to uncertainties, and disturbances [6]-[7][8][9][10]. To allowtesting platform for the flight control unmanned helicopter some 3-DOF models are developed by the Quanser[11].

The tracking error problem was examined for MIMO for non linear system and the stability evidence for closed loop system were given[12]. Considering the unmanned helicopters as a complex non linear systems, the main challenge is to control and to achieve the performance in the existence of the nonineariry, disturbances and the actuator faults[13] [14] [15].

II. EXPERIMENTAL SETUP AND MECHANICAL MODEL

The helicopter composed by a base reference such that its arm is connected with two joints. The one arm is about to rotate in the vertical axis and another one is tilt in the horizontal axis. The body of the helicopter is ascend onone of the two limits such that it is tilting in the “pitch axis”. It has two propellers along with this DC motors are provided such that depending upon the applied voltage it generates force. On the other limit the counter weight is mounted. There are three encoders are provided such that it masures the three axis (pitch, travel, elevation) with the resolution of 0.0015rad.

The block diagram of helicopter is shown in below figure.

Figure 1. 3-DOF helicopter

We know that in order to study the motion of the helicopter we need to study the dynamics of the mechanical modelled helicopter. In this model the mass is concentrated in foyr points in this four mass the two are represents counter weight and arms other two represents motor-propeller –assemblies.

A. Mathematical Modelling

The diagram of three degree of freedom helicopter is shown above. In order to describe the helicopter dynamics we use Eyler – Lagrange formula such that we can describe differential equations for the pitch angle (ρ), elevation angle (ε), travel angle (τ).

Pitch axis

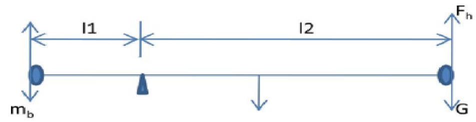

Figure 2. Pitch axis model

Assume roll to be zero,

i.e. pitch dynamics of 3 DOF helicopter is:

$J_e\ddot{\varepsilon} = l_1F_h - l_2G$

$= K_c\, l_1\, (v_1 + v_2) - T_g$

$J_e\ddot{\varepsilon} = K_c\, l_1\, (v_s) - T_g$

Where,

ε = pitch angle

$J_e = m_h\, l_1^{\,2} + m_b\, l_2^{\,2}$ (moment of enervation of system about pitch axis)

m_b= mass of balance blocks

m_h= total mass of two propeller motors

v_1 &v_2= applied voltage resulting in forces Fz&Fzrespetciveİy

K_c= force constant ofpropeller combination

l_1= distance from axis point to propeller

l_2=distancefrompivotpointtobalance

T_g = gravitational torque

Roll axis

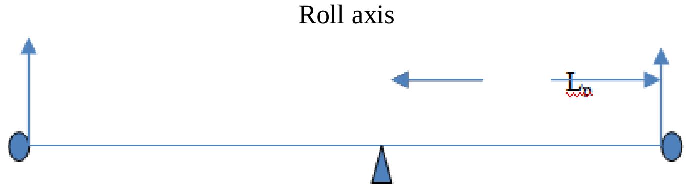

Figure 3. Roll axis model

If first motor generates high force than the second motor, helicopter will be over turned in dextrorotary.

i.e. Roll axis dynamic of 3-DOF helicopter is modeled *as*,

$J_p\, p^{\cdot} = F_1\;\, l_p - F_2\, l_p$

$= K_c\, l_p\, (v_1 - v_2)$

$J_p\, p^{\cdot} = K_c\, l_p\, v_d$

Where,

P = RoIl axis angle

$J_{p\,=}$ moment of enervation of system about roll axis

Lp = distance from axis to motor

Travel axis

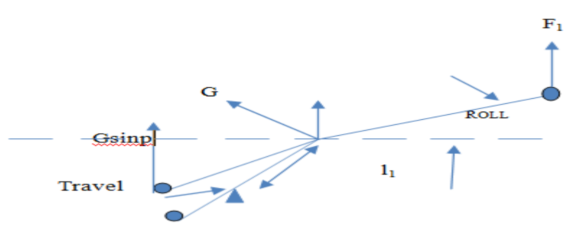

Figure 4. Travel xis model

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When travel axis slanted and over turned, the component G will produce torque such that it will produce acceleration in the travel axis. Assumingthatbodyhasrolledupbyanangle'P', the axis dynamic of 3-DOF helicopter is modifiedas,

$J_t \dot{r} = -G\sin(\rho)l_1$

$J_t \dot{r} = -K_p \sin(\rho)l_1$

Where,

$J_t \dot{r}$ = moment of eneration of system

r = rate of travel in rad/sec

K_p = required force for the helicopter to maintain flight and G

Also, roll is zero, in travel axis no force is pass.

The positive roll causes the acceleration in travel with negative direction. For designing speed controller for travel axis, model is considered for position controller Jt $\dot{r}$ = -KpSin(p) li.

III. SIMPLIFYING MODEL OF 3-DOF HELICOPTER

Assumptions for simplifying model of 3-DOF helicopter

1) All angles are scientifically small , so that linear approximation is valid.
2) Coupling dynamics is neglected.
3) Gravitational torque is neglected.
4) Friction forces are neglected.

i.e. $\ddot{\epsilon_1} = (K_c\, l_1 / J_e)\, v_s$; $\ddot{\rho} = (K_c\, l_1/l_p)\, v_d$; $\dot{r} = (G\, l_1/ J_t)$ P

Where,

$U_1 = ((v_s + v_d)/2)$, $U_2 = ((v_s - v_d)/2)$

Using laplace transform ,

$\epsilon\,(s) = (K_c\, l_1/ J_e\, s^2)\, v_s(S)$; $p(s) = (K_c\, l_p/ J_p\, s^2)\, v_d(s)$; $R(s) = (G\, R_1/ J_t\, s)\, p(s)$

Parameters to be consider,

J_e	1.8145 kgm°
J_t	1.8145 kgm*
J_p	0.0319
G	4.2591
l_1	0.88 m
l_2	0.35 m
l_p	0.17 m
K_p	12 N/V

Table 1. parameters for design

From the above equations by applying the parameter values,

$\epsilon(s) = ((5\ 8917)/s^2)\ v_s(s)$

$p(s) = ((63.9894/s^2)\ v_d(s)$

$R(s) = ((2.0055)/s)\ p(s)$

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A. Open loop response for 3-DOF helicopter

Open loop response for three axis helicopter using MATLAB simnulink was developed. The results and graph for the three axis is shown in below figure.

Pitch axis

Figure 5. pitch angle tf

The graph of amplitude vs time for pitch axis is shown below.

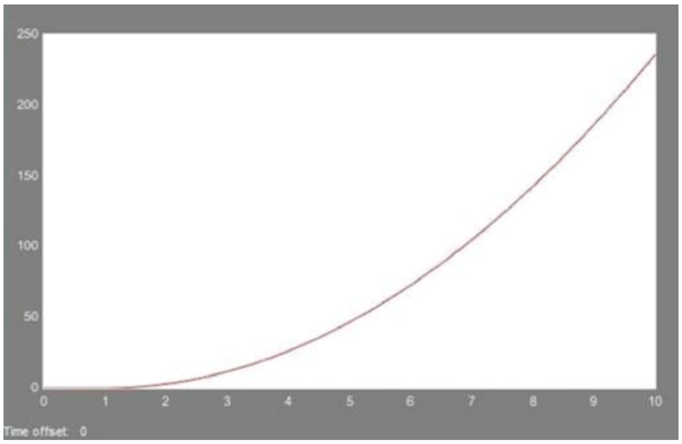

Figure 6. Response of pitch angle

Roll axis

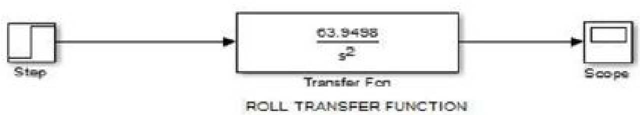

Figure 7. Roll axis tf

The graph of amplitude vs time for roll axis is shown in below figure.

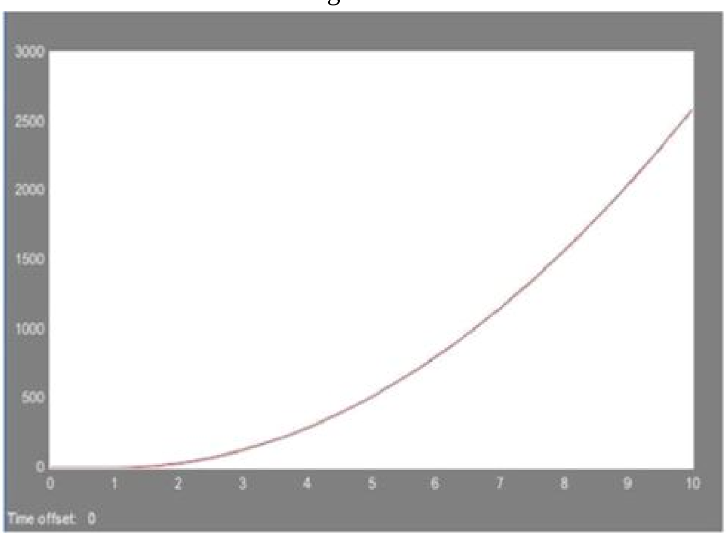

Figure 8. Response of roll angle

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Travel axis

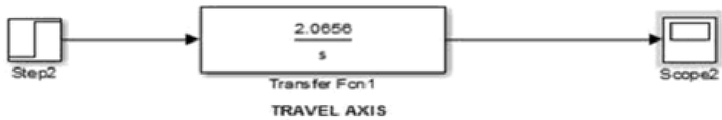

Figure 9. Travel axis tf

The graph of amplitude vs time for travel axis is shown in below figure.

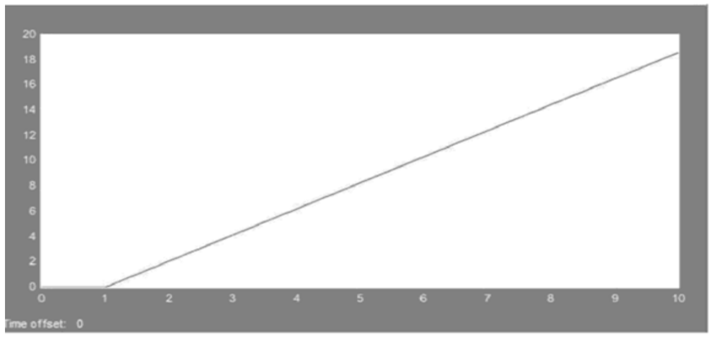

Figure 8. Response of travel angle

B. PID Control Design For 3-Dof Helicopter

The strategy to stabilizing a 3-DOF helicopter founded on PID design and the PID design is done using Skogestad tuning itictliod. i.e. using skogestad fontiula i 'c can design a PID values for the helicopter stabilization.

Skogestad tuning formula.

$G(s) = ((K^{11} - e^{\theta s})/s^2)$ (Assume θ= 0.123s)

$G(s) = ((K^{1} - e^{\theta s})/s^2)$

For elevation axis,

$\epsilon(s) = (5.8197/s^2)\ v_s\ (s)$

$k_p = 0.2367$; $k_i = 0.6$; $k_d = 1.7116$

For roll axis,

$P(s) = ((63.9408) / S^2)\ Vd(S)$

$K_p = 0.0215$; $k_i = 0.6$; $k_d = 1.7116$

For travel axis,

$R(s) = ((2.0655) / s)\ p(s)$

$K_p = 1.13$; $k_i = 0.6$

Using MATLAB simulink the PID values were added to the response for three angles such as pitch, roll, travel angle. The simulink for PID designed value are show n in below figure.

Pitch angle

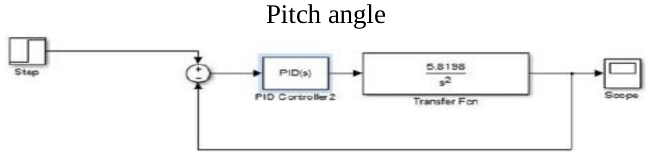

Figure 9. PID cntroler for pitch angle

Roll angle

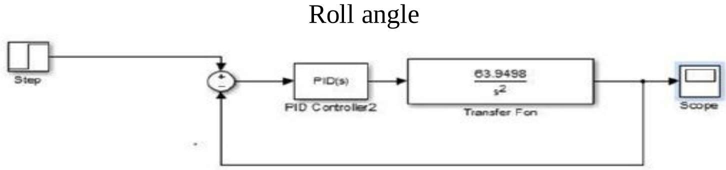

Figure 10. PID controller for roll angle

Travel axis

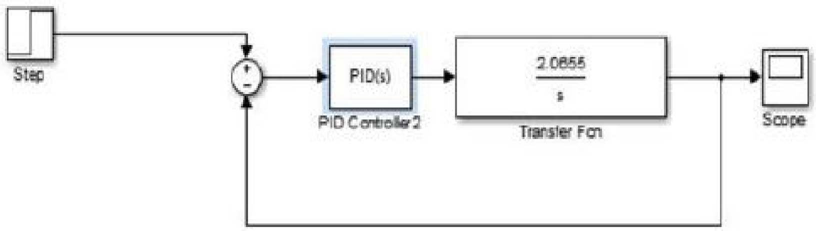

Figure 11. PID controller for travel axis

The response of the PID controller for all the three axis is shown in below figure. From the response we observed that the open loop for the system is works effectively without any disturbances**.**

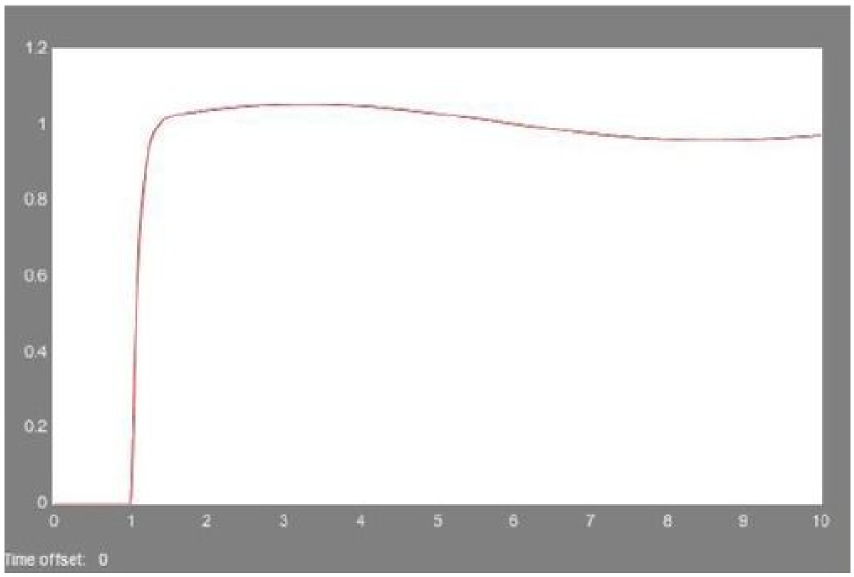

Figure 12. Response of pitch angle with PID controller

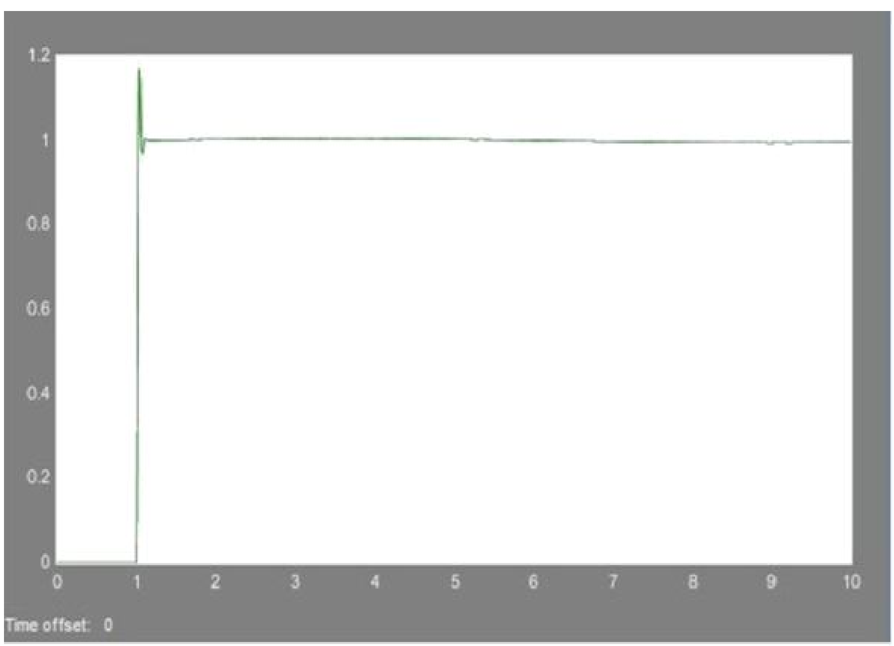

Figure 13. Response of roll angle with PID controller

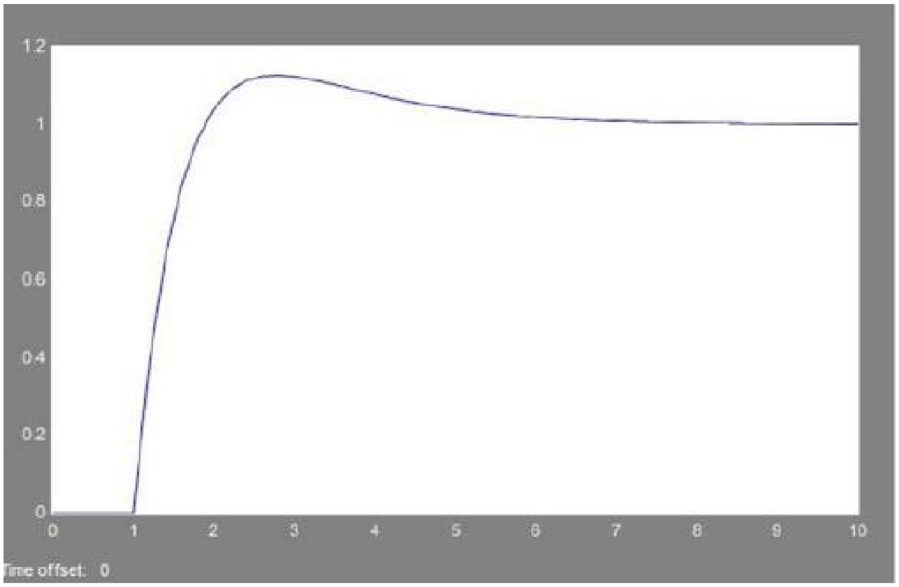

Figure 14. Response of travel axis with PID controller

IV. CONCLUSIONS

The main aim of this paper was to expansion of a PID controller using skogetsad tuning method for the 3-DOF helicopter. The results are clearly shows that the controller performs good for all the three axis such as pitch, elevation and roll axis. And also the results shows that it can control system like with working characteristics in spite of non linear systems. Forward work on the subject could include tuning of the model. Mainly the mathematical model over the three axis required forward improvement since the simulation and in real time is non identical with small considerable amount.

In addition the work could also include testing of other control. Development of a simpler LQR controller could give a comparison to the PID controller developed in this report.

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