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Practical Approach to Design a Robust Controller; Case Study on the Experiment of Twin Rotor MIMO System

Hoseung Lee[1], Hyo-Seok Kang[2] and Chang-Ho Hyun[1]

[1]IRS Lab., Dept. of Electrical Electronic and Control Engineering, Kongju National University, Republic of Korea
[2] Mathworks Korea, 13F Dukmyong Blg., 625 Teheran-ro, Gangnam-gu, Seoul, 135-741, Republic of Korea
[1]leehoseung@kongju.ac.kr, [2] khs3538@hamail.net, [1]hyunch@kongju.ac.kr

Abstract

In this paper, the robust control problem in practice is studied. For this study, the position control problem of a twin rotor MIMO system (TRMS) is considered in terms of both the simulation and the experiment. In order to present the existence of the model uncertainties and the importance of the robustness concern, the conventional input-output feedback linearization based nonlinear controller is designed with the coupled model of TRMS and its performance is analyzed through both the simulation and the experiment. Then, a robust controller, the sliding mode controller for the TRMS is designed with the same model. Through the analysis of its performance in both the simulation and the experiment, the practical weakness of the robust controller is described. Consequently, the trial and error method is recommended for the practical use of the robust controller. Some simulation and experiment results verify this study.

Keywords*: twin rotor system, robustness, uncertainties, input-output linearization, sliding mode control, practical problems*

1. Introduction

In recent years, the unmanned aerial vehicles (UAVs) have received a growing interest in both industrial and academic research. Due to their hover capability, they are useful for many civil missions such as video supervision of road traffic, surveillance of urban districts or building inspection for maintenance. Design of guidance navigation and control algorithms for the autonomous flight of UAVs have been challenging research areas because of their nonlinear dynamics and their high sensitivity to aerodynamic perturbations [1-2].

TRMS is a laboratory prototype of a flight control system which is a nonlinear multi-input-multi-output (MIMO) system. Because of the similarity about the aero-dynamics between the TRMS and a real helicopter type UAVs on certain aspects [3-5], the control of TRMS has gained a lot of research interests [6-9]. Due to the high coupling effect between two rotors, nonlinear and unstable, the control problem of the TRMS has been considered nonlinear and uncertainty of model. Dynamic modeling and optimal control of a TRMS has presented in [10]. The decoupling control of TRMS can be found in [11] with the deadbeat control technique. A novel PID control has been designed to obtain desired tracking performance [12]. To stabilize the TRMS toward the desired position, a fuzzy logic based linear quadratic regulator controller has been presented [13].

The main research objective of twin rotor system is a nonlinearity and uncertainty of the model. First, linearized model is controlled by the linear controller or original model is controlled by nonlinear controller in order to control of nonlinear model.

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However, nonlinear controllers must be designed in order to control the entire system since linear controllers are only possible to control the system at operating point. Among nonlinear controllers, robust controller techniques are often considered since there are uncertainties in the mathematical model of systems. In order to design robust controllers, it is always assumed that the boundary of uncertainties is known and how to find out the boundary of uncertainties is often ignored when the controllers are designed theoretically. However, it is not an easy problem to know the assumed range of uncertainties and the way should be guided at least.

In this paper, by practical studying of the robust controllers for systems in which model uncertainties exist (the model uncertainties that can be faced with the twin rotor control system experiment.), the practical weakness of the robust controller is presented and .the importance to know the boundary of uncertainties is emphasized. In order to present the existence of the model uncertainties and the importance of the robustness concern, the conventional input-output feedback linearization based nonlinear controller is designed with the coupled model of TRMS and its performance is analyzed through both the simulation and the experiment. Then, a robust controller, the sliding mode controller for the TRMS is designed with the same model. Through the analysis of its performance in both the simulation and the experiment, the practical weakness of the robust controller is described. Consequently, the trial and error method is recommended for the practical use of the robust controller. Some simulation and experiment results verify this study

2. Modeling of Twin Rotor System

The nonlinear TRMS primarily comprises the main and tail propellers that are driven by the independent main and tail dc motor, respectively. As shown in Figure 1, the propellers are perpendicular to each other and are joined by a beam that can rotate freely in the horizontal and vertical plane, in such a way that its ends move on spherical surfaces. The pitch (yaw) angle can be changed by adjusting the input voltage of the main (tail) motor to control the rotation speed of the main (tail) propeller.

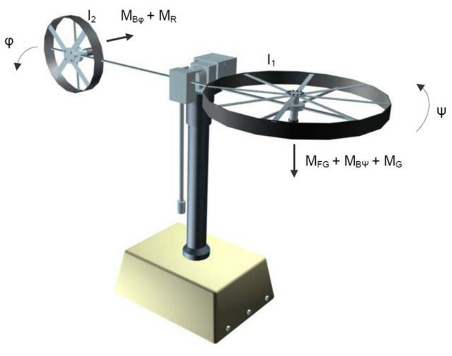


Figure 1. Twin Rotor System

2.1. Coupled Modeling of Twin Rotor System

The state space model of twin rotor system is described as following. For the vertical movement, the momentum equation can be derived as:

$$I_v.\ddot{\alpha}_v = M_1 - M_{FG} - M_{B\alpha_v} - M_G \tag{1}$$

Where, the nonlinear static characteristic

$$M_1 = a_1.\tau_1^{\ 2} + b_1.\tau_1 \tag{2}$$

The gravity momentum

$$M_{FG} = M_g.\sin\alpha_v \tag{3}$$

The friction forces momentum

$$M_{B\alpha_v} = B_{1\alpha_v}.\dot{\alpha}_v - \frac{0.0326}{2}\sin 2\alpha_v.\dot{\alpha}_h^{\ 2} \tag{4}$$

And the gyroscopic momentum

$$M_G = k_{gy}.\,\mathrm{M}_1.\,\dot{\alpha}_h.\,\cos\alpha_v \tag{5}$$

The motor and the electric control circuit are approximated by a first order transfer function thus in Laplace domain the motor momentum is described by

$$\tau_1 = \frac{k_1}{T_{11}s + T_{10}}.u_v \tag{6}$$

Similarly, the momentum equation for the horizontal movement is given as

$$I_h.\ddot{\alpha}_h = M_2 - M_{B\alpha_h} - M_R \tag{7}$$

Where the nonlinear static characteristic

$$M_2 = a_2.\tau_2^{\ 2} + b_2.\tau_2 \tag{8}$$

The friction forces momentum

$$M_{B\alpha_h} = B_{1\alpha_h}.\,\dot{\alpha}_h \tag{9}$$

And M_R is the cross reaction momentum approximated by

$$M_R = \frac{k_c(T_0 s + 1)}{(T_p s + 1)}.\mathrm{M}_1 \tag{10}$$

Again the DC motor with the electrical circuit is given by

$$\tau_2 = \frac{k_2}{T_{21}s + T_{20}}.\,u_h \tag{11}$$

The complete dynamics of the twin rotor system (1-11) can be represented in the state space form as follows

$$\frac{d\alpha_v}{dt} = \dot{\alpha}_v$$

$$\frac{d\dot{\alpha}_v}{dt} = \frac{a_1}{I_v}\tau_1^{\ 2} + \frac{b_1}{I_v}\tau_1 - \frac{Mg}{I_v}\sin\alpha_v - \frac{B_{1\alpha_v}}{I_v}\dot{\alpha}_v + \frac{0.0326}{2I_v}\sin(2\alpha_v)\dot{\alpha}_h^{\ 2}$$
$$-\frac{k_{gy}}{I_v}a_1\cos(\alpha_v)\dot{\alpha}_h\tau_1^{\ 2} - \frac{k_{gy}}{I_v}b_1\cos(\alpha_v)\dot{\alpha}_h\tau_1$$

$$\frac{d\alpha_h}{dt} = \dot{\alpha}_h$$

$$\frac{d\dot{\alpha}_h}{dt} = \frac{a_2}{I_h}\tau_2^{\ 2} + \frac{b_2}{I_h}\tau_2 - \frac{B_{1\alpha_h}}{I_h}\dot{\alpha}_h - \frac{k_c a_1}{I_h}1.75\tau_1^{\ 2} - \frac{1.75}{I_h}k_c b_1\tau_1$$

$$\frac{d\tau_1}{dt} = -\frac{T_{10}}{T_{11}}\tau_1 + \frac{k_1}{T_{11}}u_v$$

$$\frac{d\tau_2}{dt} = -\frac{T_{20}}{T_{21}}\tau_2 + \frac{k_2}{T_{21}}u_h \tag{12}$$

The output is given by $y = [\alpha_v \quad \alpha_h]^T$

Where,

α_v : Pitch (elevation) angle

α_v : Yaw (azimuth) angle

τ_1 : Momentum of main rotor

τ_2 : Momentum of tail rotor

Define the state variables as $x_1 = \alpha_v$ is the pitch angle, $x_3 = \alpha_h$ is the yaw angle, $x_2 = \Omega_v$ is the pitch angular velocity in the vertical plane, $x_4 = \Omega_h$ is the yaw angular velocity in the horizontal plane, $x_5 = \tau_1$ is the momentum of main motor and $x_6 = \tau_2$ is the momentum of tail motor.

The complete state equations of the TRMS can be derived as

$$\frac{dx_1}{dt} = x_2$$

$$\begin{aligned}\frac{dx_2}{dt} = {} & \frac{a_1}{I_v}x_5^2 + \frac{b_1}{I_v}x_5 - \frac{Mg}{I_v}\sin x_1 - \frac{B_{1\alpha_v}}{I_v}x_2 \\ & + \frac{0.0326}{2I_v}\sin(2x_2)x_4^2 - \frac{k_{gy}}{I_v}a_1\cos(x_1)x_4x_5^2 \\ & - \frac{k_{gy}}{I_v}b_1\cos(x_1)x_4x_5\end{aligned}$$

$$\frac{dx_3}{dt} = x_4$$

$$\frac{dx_4}{dt} = \frac{a_2}{I_h}x_6^2 + \frac{b_2}{I_h}x_6 - \frac{B_{1\alpha_h}}{I_h}x_4 - \frac{k_c a_1}{I_h}1.75x_5^2 - \frac{1.75}{I_h}k_c b_1 x_5$$

$$\frac{dx_5}{dt} = -\frac{T_{10}}{T_{11}}x_5 + \frac{k_1}{T_{11}}u_v$$

$$\frac{dx_6}{dt} = -\frac{T_{20}}{T_{21}}x_6 + \frac{k_2}{T_{21}}u_h \tag{13}$$

3. Feedback Linearization Based Controller for the Coupling Model Based on Twin Rotor System

In this section, we design a feedback linearization based controller for the twin rotor system derived in the previous chapter. The main rotor portion and the tail rotor portion are considered separately to design a vertical position controller and a horizontal position controller.

3.1. Design of Feedback Linearization Based Controller

Block diagram of the twin rotor system is shown as Figure 2. It shows that TRMS has two inputs and outputs. As

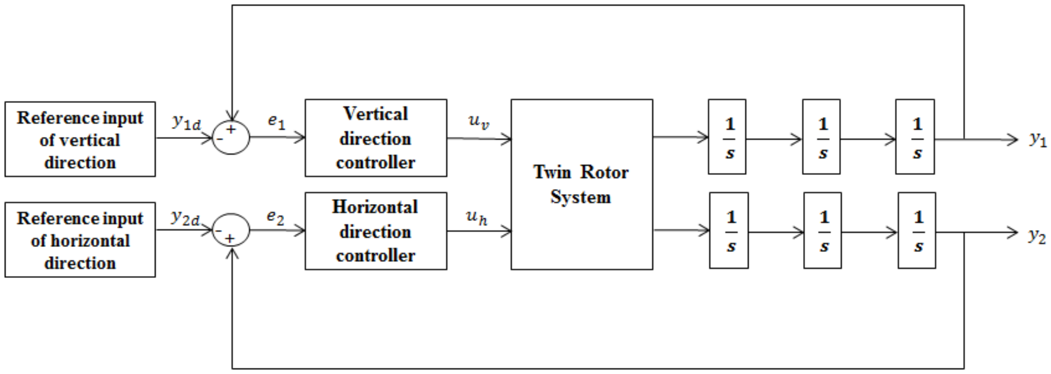


Figure 2. Feedback Linearization Block Diagram of Twin Rotor System

The input-output feedback linearization based controller uses a virtual controller for the cancellation of the nonlinear term of systems. The following shows the process to design the input-output feedback linearization based controller.

$$
\begin{aligned}
y_1 &= x_1 \\
\frac{dy_1}{dt} &= \frac{dx_1}{dt} = x_2 \\
\frac{d^2 y_1}{dt^2} &= \frac{dx_2}{dt} = \frac{a_1}{I_v} x_5^2 + \frac{b_1}{I_v} x_5 - \frac{M_g}{I_v}\sin(x_1) - \frac{B_{1\alpha_v}}{I_v} x_2 \\
&\quad + \frac{0.0326}{2I_v}\sin(2x_2)x_4^2 - \frac{k_{gy}}{I_v} a_1 \cos(x_1) x_4 x_5^2 \\
&\quad - \frac{k_{gy}}{I_v} b_1 \cos(x_1) x_4 x_5 \\
\frac{d^3 y_1}{dt^3} &= \frac{d^2 x_2}{dt^2} = 2\frac{a_1}{I_v} x_5 \dot{x}_5 + \frac{b_1}{I_v}\dot{x}_5 - \frac{M_g}{I_v}\cos(x_1)\dot{x}_1 - \frac{B_{1\alpha_v}}{I_v}\dot{x}_2 \\
&\quad + \frac{0.0326}{I_v}\left\{\cos(2x_2)\dot{x}_2 x_4^2 + \sin(2x_2) x_4 \dot{x}_4\right\} \\
&\quad - \frac{k_{gy} a_1}{I_v}\left\{-\sin(x_1)\dot{x}_1 x_4 x_5^2 + \cos(x_1)\dot{x}_4 x_5^2 + 2\cos(x_1) x_4 x_5 \dot{x}_5\right\} \\
&\quad - \frac{k_{gy}}{I_v} b_1 \left\{-\sin(x_1)\dot{x}_1 x_4 x_5 + \cos(x_1)\dot{x}_4 x_5 + \cos(x_1) x_4 \dot{x}_5\right\}
\end{aligned}
\tag{14}
$$

In equation (3), to organize only the part related to $\dot{x}_5$ with input vector u_v

$$
\left\{2\frac{a_1}{I_v} x_5 + \frac{b_1}{I_v} - \frac{k_{gy}}{I_v} 2\cos(x_1) x_4 x_5 - \frac{k_{gy} b_1}{I_v}\cos(x_1) x_4\right\}\dot{x}_5 \tag{15}
$$

Where, After defining $\left\{2\frac{a_1}{I_v} x_5 + \frac{b_1}{I_v} - \frac{k_{gy}}{I_v} 2\cos(x_1) x_4 x_5 - \frac{k_{gy} b_1}{I_v}\cos(x_1) x_4\right\} = f_1(x)$, equation (15) changes to equation (16)

$$f_1(x)\left(-\frac{T_{10}}{T_{11}}+\frac{k_1}{T_{11}}u_v\right) \tag{16}$$

In equation (3), the term with the exception of $f_1(x)$ is defined as $g_1(x)$, given by

$$\frac{d^3y_1}{dt^3}=g_1(x)+f_1(x)\left(-\frac{T_{10}}{T_{11}}x_5+\frac{k_1}{T_{11}}u_v\right) \tag{17}$$

By the input-output linearization control law u_v is represented

$$u_v=\left\{\frac{T_{10}}{T_{11}}x_5+\frac{1}{f_1(x)}\left(-g_1(x)+v_1\right)\right\}\frac{T_{11}}{k_1} \tag{18}$$

Where

$$\begin{aligned} g_1(x)=&\left(-\frac{M_g}{I_v}\cos(x_1)+\frac{k_{gy}}{I_v}a_1\sin g(x_1)x_4x_5^2+\frac{k_{gy}}{I_v}b_1\sin(x_1)x_4x_5\right)\dot{x}_1\\ &+\left(-\frac{B_{1a_v}}{I_v}+\frac{0.0326}{I_v}\cos(2x_2)x_4^2\right)\dot{x}_2\\ &+\left(\frac{0.0326}{I_v}\sin(2x_2)x_4-\frac{k_{gy}}{I_v}a_1\cos(x_1)x_5^2\right)\dot{x}_4 \end{aligned}$$

Output tracking control input v_1 of vertical direction is

$$v_1=y_{1d}^{(3)}-F_1e_1-F_2e_2-F_3e_3 \tag{19}$$

Where, $e_1=y_1-y_{1d}$, y_{1d} is desired output of vertical direction.

From equation (19) the error dynamics as follows

$$-F_1e_1-F_2\dot{e}_1-F_3\ddot{e}_1-e_1^{(3)} \tag{20}$$

Where, F_1, F_2, F_3 are tracking control gain of vertical direction controller.

Using the pole placement of linear control techniques to find the tracking control gain and finding the characteristic equation of desired pole as follow

$$(s+p_1)(s+p_2)(s+p_3)=0 \tag{21}$$

Where, $-p_1$, $-p_2$, $-p_3$ is desired pole.

Equation (21) is rewritten by

$$s^3+(p_1+p_2+p_3)s^2+(p_1p_2+p_2p_3+p_3p_1)s+p_1p_2p_3=0 \tag{22}$$

Laplace transform in (20)

$$s^3E_1(s)-F_3s^2E_1(s)-F_2sE_1(s)-F_1E_1(s)=0 \tag{23}$$

And then

$$s^3-F_3s^2-F_2s-F_1=0 \tag{24}$$

Tracking control gain through comparing the coefficient of (22) and (24) is shown as

$$F_3=p_1+p_2+p_3,\ F_2=p_1p_2+p_2p_3+p_3p_1,\ F_1=p_1p_2p_3$$

In the same manner, we shall differentiate horizontal output y_2 of equation (13) again and again until appear input vector u as follows:

$$y_2 = x_3$$
$$\frac{dy_2}{dt} = \frac{dx_3}{dt} = x_4$$
$$\frac{d^2y_2}{dt^2} = \frac{dx_4}{dt} = \frac{a_2}{I_h}x_6^{\ 2} + \frac{b_2}{I_h}x_6 - \frac{B_{1\alpha_h}}{I_h}x_4 - \frac{k_c a_1}{I_h}1.75x_5^{\ 2} - \frac{k_c b_1}{I_h}1.75x_5$$
$$\frac{d^3y_2}{dt^3} = 2\frac{a_2}{I_h}x_6\dot{x}_6 + \frac{b_2}{I_h}\dot{x}_6 - \frac{B_{1\alpha_h}}{I_h}\dot{x}_4 - 2\frac{k_c a_1}{I_h}1.75x_5\dot{x}_5 - \frac{k_c b_1}{I_h}1.75\dot{x}_5 \qquad (25)$$

In equation (25), to organize only the part related to $\dot{x}_6$ with input vector u_h

$$\left(2\frac{a_2}{I_h}x_6 + \frac{b_2}{I_h}\right)\dot{x}_6 \qquad (26)$$

Where, define $\left(2\frac{a_2}{I_h}x_6 + \frac{b_2}{I_h}\right) = f_2(x)$, equation (26) change to equation (27)

$$\frac{d^3y_2}{dt^3} = g_2(x) + f_2(x)\left(-\frac{T_{20}}{T_{21}}x_6 + \frac{k_2}{T_{21}}u_h\right) \qquad (27)$$

By the input-output linearization control law u_h is represented

$$u_h = \left\{\frac{T_{20}}{T_{21}}x_6 + \frac{1}{f_2(x)}\left(-g_2(x) + v_2\right)\right\}\frac{T_{21}}{k_2} \qquad (28)$$

Where

$$g_2(x) = -\frac{B_{1\alpha_h}}{I_h}\dot{x}_4 - \left(2\frac{k_c a_1}{I_h}1.75x_5 + \frac{k_c b_1}{I_h}1.75\right)\dot{x}_5$$

Output tracking control input v_2 of horizontal direction is

$$v_2 = y_{2d}^{\ (3)} - F_4e_4 - F_5e_5 - F_6e_6 \qquad (29)$$

Where, $e_2 = y_2 - y_{2d}$, y_{2d} is desired output of horizontal direction.

From equation (29) the error dynamics as follows

$$-F_4e_2 - F_5\dot{e}_2 - F_6\ddot{e}_2 - e_2^{\ (3)} \qquad (30)$$

Where, F_4, F_5, F_6 are tracking control gain of horizontal direction controller.

Using the pole placement of linear control techniques to find the tracking control gain and finding the characteristic equation of desired pole as follow

$$(s + p_4)(s + p_5)(s + p_6) = 0 \qquad (31)$$

Where, $-p_4$, $-p_5$, $-p_6$ is desired pole.

Equation (31) is rewritten by

$$s^3 + (p_4 + p_5 + p_6)s^2 + (p_4p_5 + p_5p_6 + p_6p_4)s + p_4p_5p_6 = 0 \qquad (32)$$

Laplace transform in (20)

$$s^3E_2(s) - F_6s^2E_2(s) - F_5sE_2(s) - F_4E_2(s) = 0 \qquad (33)$$

And then

$$s^3 - F_6s^2 - F_5s - F_4 = 0 \qquad (34)$$

Tracking control gain through comparing the coefficient of (32) and (34) is shown as

$$F_6 = p_4 + p_5 + p_6,\ F_5 = p_4p_5 + p_5p_6 + p_6p_4,\ F_4 = p_4p_5p_6$$

4. Design of Sliding Mode Controller of the Twin Rotor System Considering the Uncertainty of the Coupled Model

In this section, we design a sliding mode controller considering uncertainty of coupled model of the twin rotor system.

4.1. Design of Feedback Linearization Controller

Sliding mode control is important to determine the conditions to reach the state in the slide plane. These conditions are referred to as a reaching condition. Let us propose a positive definite function in order to obtain reaching condition

$$V = \frac{1}{2} S^2(x) \tag{35}$$

Where $S(x)$ is sliding surface, x is state vector of system. The reaching condition which is existed sliding mode is obtained as follow

$$\dot{V}(x,t) = S(x)\dot{S}(x) < 0 \qquad for \qquad x \in R^n - S \tag{36}$$

Supposing x is any position in R^n excluding the sliding surface $S(x)$, x is reached $S(x)=0$ because $\dot{V}(x,t) < 0$.

The following is a design process of the sliding mode controller. The sliding surface in the vertical direction written by

$$\begin{aligned} S_1(x_1) &= \left(\frac{d}{dt} + \lambda_1 \right)^{n_1 - 1} \tilde{x}_1 \\ &= \left(\frac{d}{dt} + \lambda_1 \right)^2 e_1 \\ &= \frac{d^2 e_1}{dt^2} + 2\lambda_1 \frac{de_1}{dt} + \lambda_1^2 \end{aligned} \tag{37}$$

Where, n_1 is system order of main rotor, λ_1 is positive constant, $\tilde{x}_1 = e_1 = y_1 - y_{1d}$

Sliding mode controller in the vertical direction applied to the sliding surface is defined as follows

$$u_v = v_1 - k_1 sat(S_1) \tag{38}$$

Where, v_1 is input-output linearization of the vertical tracking controller, k_1 is sliding mode controller gain of vertical direction.

The sliding surface in the horizontal direction written by

$$\begin{aligned} S_2 &= \left(\frac{d}{dt} + \lambda_2 \right)^{n_2 - 1} \tilde{x}_2 \\ &= \left(\frac{d}{dt} + \lambda_2 \right)^2 e_2 \\ &= \frac{d^2 e_2}{dt^2} + 2\lambda_2 \frac{de_2}{dt} + \lambda_2^2 \end{aligned} \tag{39}$$

Sliding mode controller in the horizontal direction applied to the sliding surface is defined as follows

$$u_h = v_2 - k_2 sat(S_2) \tag{40}$$

Where, v_2 is input-output linearization of the horizontal tracking controller, k_2 is sliding mode controller gain of horizontal direction.

5. Simulation and Experimental of Feedback Linearization Controller and Sliding Mode Controller

The performance of the TRMS controlled by using our proposed controllers is studied for the position control problem. The actual experiment is applied to the actual twin rotor system based on the results of the simulations. The operating time is set to 100[sec], reference input of vertical position is set 0.5[rad] and the reference input of the horizontal position is set to 0.4[rad].

The TRMS in laboratory is setup as in Figure 2. The controllers are implemented in Windows XP using Simulink and a proprietary real-time kernel included with the TRMS system.

The reference signals to the vertical and horizontal part are fed to the controller together with the actual position of the TRMS. The output from the controller is the voltage to the DC-motor which is transformed by the voltage mapping before it is sent to the real time task which takes care of all the communication with the TRMS.

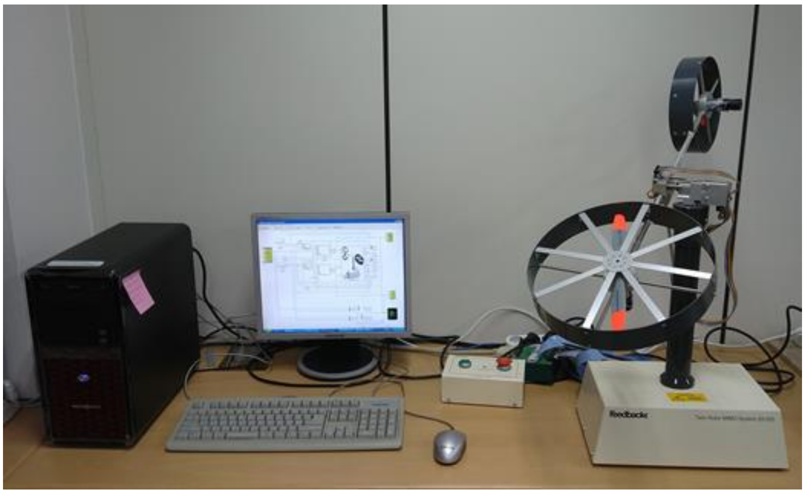


Figure 2. Twin Rotor System in Laboratory

5.1. Simulation and Experimental of Feedback Linearization Controller

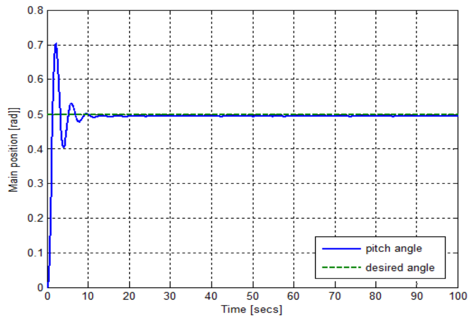
In the feedback linearization controller for vertical subsystem of TRMS, choose the value of three gains as follow:

$$F_1 = 535,\ F_2 = 156,\ F_3 = 180$$

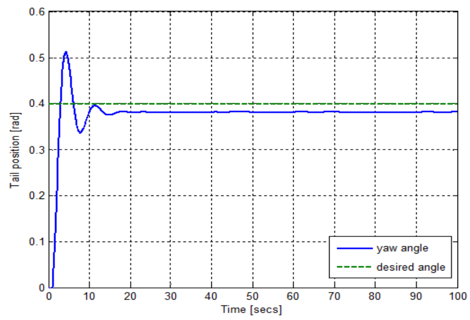
In the horizontal subsystem, the value of three gains is chosen as:

$$F_4 = 320,\ F_2 = 222,\ F_3 = 360$$

For the angle tracking, a step function is used as the reference commands for the pitch and yaw angles of the twin rotor system. In simulation, the tracking response in Figure 3 demonstrates that the feedback linearization controllers are able to track the reference pitch and yaw angles satisfactory. However, the steady state error of real time twin rotor system is found in Figure 4. It is recognizable that there exist the model uncertainties in TRMS model.

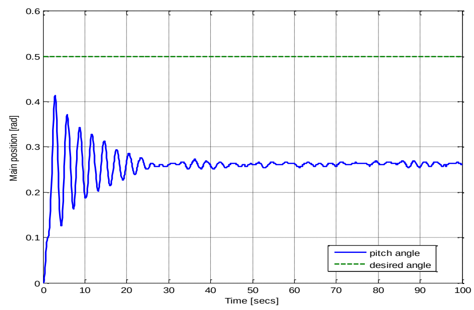


(a) Vertical position

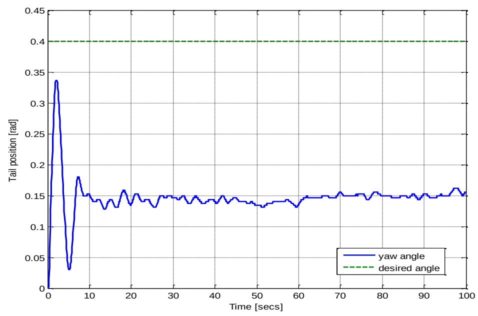


(b) Horizontal position

Figure 3. Step Response of the Feedback Linearization Controller of the Twin Rotor System Using the Trial-and-Error Method

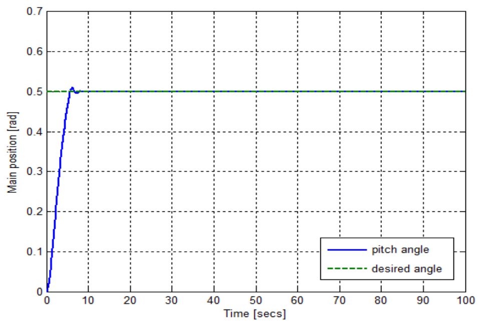


(a) Vertical position

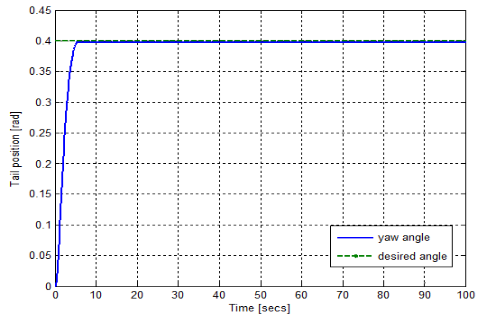


(b) Horizontal position

Figure 4. Step Response of the Feedback Linearization Controller of Real Time the Twin Rotor System



(a) Vertical position



(b) Horizontal position

Figure 5. Step Response of the Sliding Mode Controller of the Twin Rotor System Using the Trial-and-Error Method

5.2. Simulation and Experimental of Sliding Mode Controller

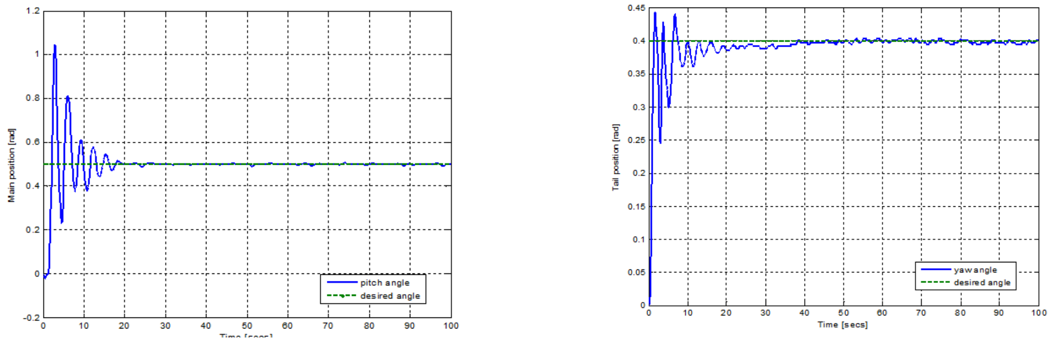
In the feedback linearization controller for vertical subsystem of TRMS, choose again the value of three gains and sliding surface constant and sliding controller gain as follow:

$$F_1 = 35,\ \ F_2 = 156,\ \ F_3 = 180,\ \ \lambda_1 = 20,\ \ k_1 = 10$$

In the horizontal subsystem, the value of three gains and sliding surface constant and sliding controller gain are chosen as:

$$F_4 = 33,\ \ F_2 = 92,\ \ F_3 = 60\ \ \lambda_2 = 20,\ \ k_2 = 6$$

In simulation and experimental, the tracking response depicted in Figure 5 and 6 demonstrate that the feedback linearization controllers are able to track the reference pitch and yaw angles satisfactory.



(a) Vertical position (b) Horizontal position

Figure 6. Step Response of the Sliding Mode Controller of Real Time the Twin Rotor System

6. Conclusion

In this paper, the practical approach to design a robust controller was studied. For this study, the position control problem of a twin rotor MIMO system (TRMS) was considered in terms of both the simulation and the experiment. The existence of the model uncertainties and the importance of the robustness concern are proved using both simulation and experiment first. Then, the practical weakness of the robust controller was verified using both simulation and experiment. To present these two studies, the conventional input-output feedback linearization based nonlinear controller was designed with the coupled model of TRMS and a robust controller, the sliding mode controller for the TRMS was designed with the same model. Consequently, by recommending the trial and error method for the practical use of the robust controller with some simulation and experiment, this study was verified.

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Authors

Hoseung Lee, He received the B.S and master's degree and now doctoral course in Electrical Electronic and Control Engineering form Kongju National University, Korea in 2013. His main research interests are drone and various control theory.

Hyo-Seok Kang, He received the B.S. in Electronic Engineering from Sunmoon University Asan, Korea in 2009 and a Combined Master's and Doctoral Course student in Electrical and Electronic Engineering at Yonsei University in 2014. He has joined Mathworks Korea as training engineer. His main research interests are adaptive control and fuzzy control and its applications.

Chng-Ho Hyun, He received the B.S. in Control and Measurement engineering from Kwangwoon University, Korea in 1999 and a Combined Mster's and Doctoral Course student in Electrical and Electronic Engineering at Yonsei University in 2008. He joined Samsung Advanced Institute of Technology in 2009. He is currently a professor at Kongju National University. His main research interests are intelligent control, fuzzy control system, robot control and robot engineering.