A Multivariable Twin-Rotor System Control Design

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Abstract—This paper presents the design of a Multi-Input Multi-Output (MIMO) PID controller for a twin-rotor MIMO system. A multivariable control system consisting of two loops is designed for a non-linear system with two inputs and two outputs. The designed controllers have been tested on a simulated model with different possibilities and real-time results were taken. The designed PID controller efficiently controls the loops of the system and does not suffer from any process interactions. The results indicate that the performance of the PID controllers is excellent and both the transient and the steady-state enactment are adequate. The yaw and pitch rotor's real-time responses are almost the same as the desired ones.

Keywords-PID controller; MIMO; non-linear system

I. INTRODUCTION

Helicopters have been widely used for fast or immediate transports like medical emergencies, personal use, crime prevention, traffic conditioning, fire detection, etc. [1]. The Twin Rotor MIMO System (TRMS) can be related to the helicopters in many aspects, e.g. the complex structure, nonlinearity, and cross coupling rotors' behavior. The TRMS due to the coupling effect suffers from many issues regarding the transversal vibration in beam. Many studies have been carried out to handle this issue by providing mathematical models representing unbalanced external forces. The implementation of the discrete time model has attracted attention [2, 3]. For a complex system, an adaptive controller was designed [4, 5] and implemented in order to get the desired output of the uncertain system and the errors were successfully tracked by the adaptive self-tuning control scheme. Adaptive natured control motivation led the authors in [6, 7] to compute a mathematical model of TRMS which is based on the adaptive control principle and the on-line identifier ARMAX model. The two multivariable adaptive controllers were implemented into the system and compared with the fixed gain PID controller. The controllers showed very good results in error tracking with Self-Tuning Control (STC) having external disturbances.

A robust technique was used in [8, 9]. A fuzzy integral sliding controller was utilized in the vertical subsystem and on the horizontal plant a fuzzy sliding controller was implemented to track the errors. In [10-12], a Particle Swam Optimization (PSO)-based control technique was implemented to a TRMS with a PID controller that helped tune the PID controller at optimal point. PSO-based controller with PID was also used in [11] with the addition of a compensator. Although the compensator-based technique tracked the errors efficiently, the overall system was very complex to implement. An autonomous adaptive controller implemented with the PID controller to mitigate the oscillation errors was proposed in [13] to control TRMS. The comparison results showed that the autonomous adaptive controller with frictional order PID was more suitable than the integral order PID controller. A predictive control approach used for wind turbine speed control was presented in [14] and an optimizated control of the hydraulic actuator was presented in [15] with PID controllers by minimizing integral time. A multivariable PID controller was proposed in [16-18] with the ability to operate autonomously and the yaw and pitch angle were efficiently controlled. Linear Parameter Varying (LPV) modeling [19] implements a control technique to the TRMS that takes care of the errors [18]. This controller performs well with fast

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response, but having the design complexity as its main drawback of its implementation. A self-tuned online parameter estimation-based controller was designed in [20] for the TRMS kit and its simulation results were compared with real time data. The online estimation-based self-tuned adaptive controller needs to have real time data and varying parameters' exact computation. The ARX model was utilized to design the online estimation-based controller in almost all the cases.

This paper presents the design of a Multi-Input Multi-Output (MIMO) PID controller for a twin rotor MIMO system. A multivariable control that consists of two loops for a non-linear system with two inputs and two outputs was designed. The designed controller was tested on a simulated model and the results were compared with real data. The designed PID controller efficiently controls the loops of the system and does not suffer from any process interactions.

II. TWIN ROTOR MIMO SYSTEM MODEL

A basic TRMS model (TMRS-33-220) is illustrated in Figure 1. The system is standing with the help of a tower, arranged in such a way that the model exhibits its rotary motion. The model can move in two directions, vertically and horizontally and the motion of the free-fall beam generates force. The beam pivoted on the tower is attached via bearings. These bearings allow the free movement in the vertical and horizontal direction within some limitations [21] (it cannot move freely up to 360^o). If the beam is locked, the model cannot roll. Two rotors are also attached on end points of the free-fall beam. The ends are categorized as the main and tail rotors.

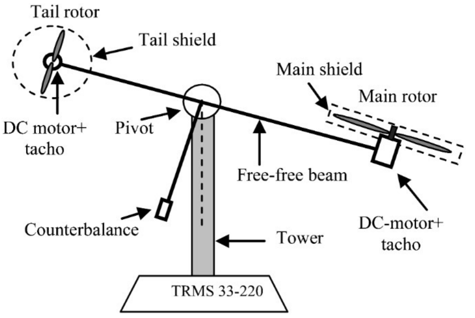

Fig. 1. The TRMS model.

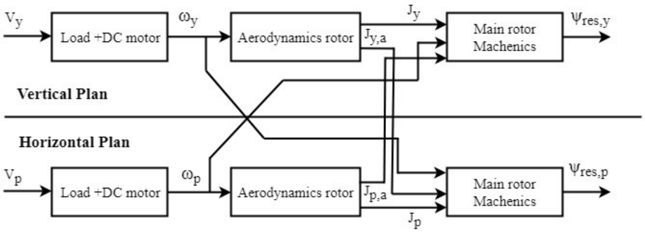

Fig. 2. Block diagram of the TRMS.

The mathematical model of the TRMS is quite complex and difficult to implement. For convenience, the overall model is separated in small units for decoupling [22]. The overall model is divided into six parts as shown in Figure 2. The sub model load+ DC motor has ω_y and ω_p as inputs. The aerodynamic rotor block has the ω_y and ω_p as inputs and its outputs are aerodynamic torques $J_{p,}$ J_y $J_{p,\mathrm{a}}$. The last blocks are the mechanics of the tail and main rotors. Their outputs are azimuth angles $\psi_{res,\mathrm{y}}$ and $\psi_{res,\mathrm{p}}$. The first order differential equation expresses the dynamics of the propeller sub system. The simplification of the TRMS can be made by two point mass system.

III. THE PROPOSED CONTROLLER DESIGN

For the TRMS model, the motion of the system can be described in terms of main and tail rotors as shown in (1)-(2):

$$\frac{ds_v}{dt} = l_y S_b F_v(\omega_y) - \lambda_v K_v$$
$$+g[(X-Y)\cos\phi_v - Z\sin\phi_v] - \frac{1}{2}\lambda^2 (X+Y+Z)\sin 2\phi_v \quad (1)$$

$$\lambda_v = S_v + \frac{J_{pr}\omega_p}{J_v} \quad (2)$$

where S_v is the angular momentum around the horizontal plane (in the vertical plane). S_b , is the balance scale, and

$$\frac{d\phi_v}{dt} = \lambda_v$$

$$\frac{ds_h}{dt} = l_p S_b F_h(\omega_p)\cos\phi_v - \lambda_h K_h \quad (3)$$

where

$$\lambda_h = \frac{S_h + J_{yr}\omega_y \cos\phi_v}{J_h} \Rightarrow$$

$$\lambda_h = \frac{S_h + J_{yr}\omega_y \cos\phi_v}{P\sin^2\phi_v + Q\cos^2\phi_v + R} \quad (4)$$

where S_h is the angular momentum around the vertical plane of the beam (in the horizontal plane), J_{pr} is the moment of inertia (in the DC motor tail propeller subsystem), J_{yr} is the moment of inertia (in the DC motor main propeller subsystem), and ω_y and ω_p describe the system's velocity for nonlinear system's output voltage. Figure 3 shows the block diagram which mathematically can be expressed as:

$$\frac{dD_{vv}}{dt} = \frac{1}{T_{yr}}(-D_{vv} + D_v)$$

$$\omega_y = p_v(D_{vv}) \quad (5)$$

$$\frac{dD_{hh}}{dt} = \frac{1}{T_{pr}}(-D_{hh} + D_h)$$

$$\omega_p = P_h(D_{hh}) \quad (6)$$

where T_{yr} and T_{pr} are main and tail rotor propeller system time constants.

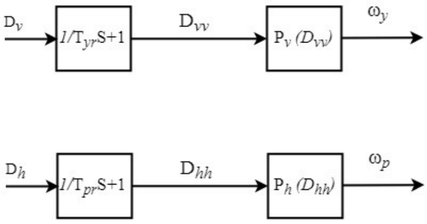

Fig. 3. Block diagram.

The PID controllers combine the advantages of the individual P, I, and D controllers. The above system structure is composed of two summing points. Their function is to determine the error signal which is the difference between the set point and the measured variable. The error signal is amplified via a proportional amplifier and again by integral and derivative amplifiers. Secondly, the additions of the outputs from the amplifiers are also carried out by the summing points. The three term function can be expressed as:

$$P_{out} = K_g E_g + K_g K_i \int_0^t E_g dt + K_g K_d \frac{dE_g}{dt} + P(0) \quad (7)$$

Three term controllers were connected in series and in parallel. When these three controllers were connected in parallel, the PID controller is considered to be non-interacting. In this situation, the interaction of the proportional control action with the integral and derivative control action is neglected. Most of the PID controllers are available in serial or interaction configuration. Due to the interaction fact, the derivative precedes the proportional controller by 90°. The PID control model is discussed in detail below.

A. PID Controller Model

The simulation model of the PID controller for the main rotor is shown in Figure 4. Figure 5 shows the tail rotor configuration. Their parameters are given in Tables I and II respectively.

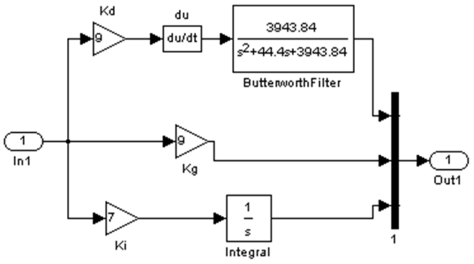

Fig. 4. Main-rotor controller.

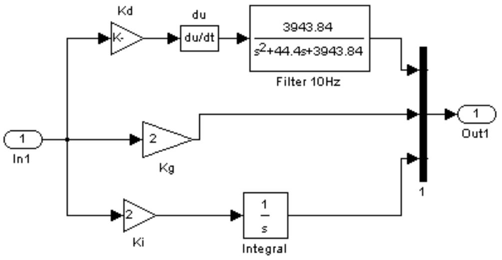

Fig. 5. Tail-rotor controller.

TABLE I. MAIN AND TAIL ROTOR PARAMETERS

Parameter	Value
Moment of inertia	6.8e^{-2}Kgm^2
Torque c_1(psi)	6e^{-3}Nm
Torque c_2(psi)	1e^{-3}Nm
Static characteristics d_1,c_1	0.0134,0.0924
Parameter K_{gy}	0.05s/rad
Movement of gravity M_{gy}	0.32Nm

TABLE II. TAIL ROTOR PARAMETERS

Parameters	Values
Moment of inertia	2e^{-2}Kgm^2
Torque c_1(psi)	1e^{-1}Nm
Torque c_2(psi)	1e^{-3}Nm
Static characteristics d_2,c_2	0.01,0.09

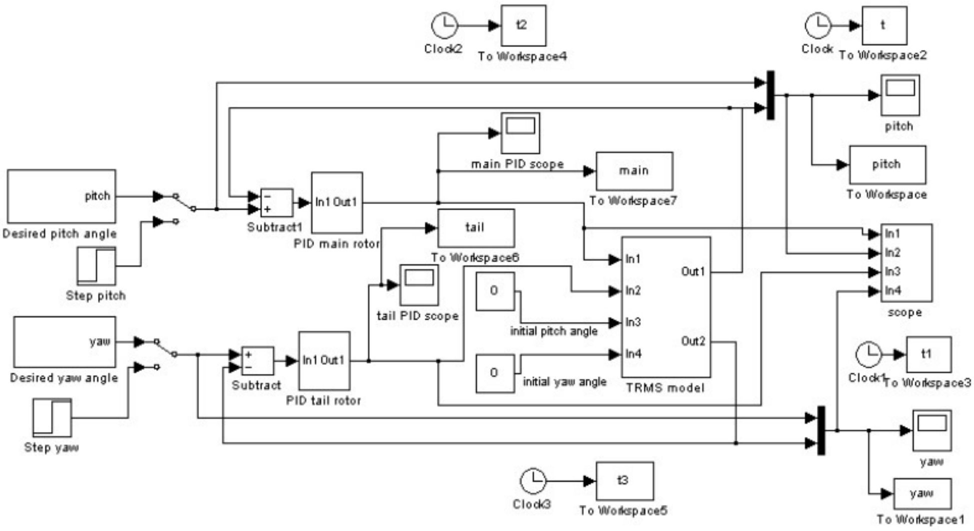

Fig. 6. Simulation model for pitch and yaw rotor TRMS system with PID controllers.

B. TRMS Model

The simulation model of the TRMS with overall connections and control methodology is given in Figure6.

IV. SIMULATION RESULTS AND DISCUSSION

The simulation results for the pitch rotor PID controller with K_g, K_d and K_i being the proportional, derivative and integral parameters having values 09, 09, 07 respectively are given in Figure 7. The simulation results for yaw rotor PID controller with K_g, K_d, and K_i having values 02, 10, 02 respectively are given in Figure 8.

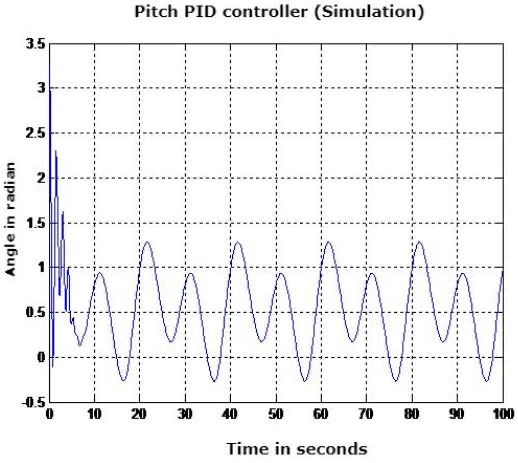

Fig. 7. Pitch PID controller simulation.

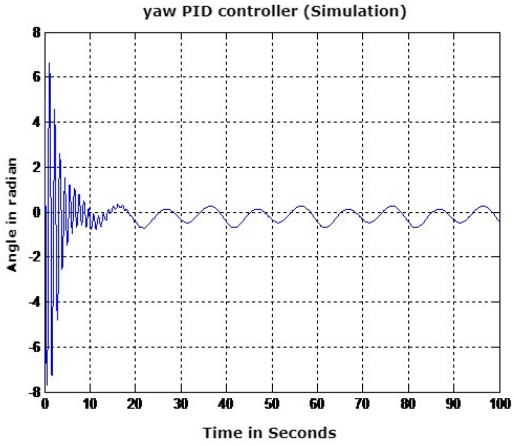

Fig. 8. Yaw PID controller simulation.

The plots of tail and main rotor are given in Figures 9 and 10 respectively. Figure 9 shows the desired and actual yaw angle in the time interval 0-100s. The designed behavior of the yaw angle for the TRMS versus time is presented with different line patterns for desired and actual position. It can be seen that there is no major difference. Figure 10 shows the desired and actual pitch angle during the time interval 0-100s. The designed behavior of the yaw angle for the TRMS versus time is presented with different line patterns for the desired and actual positions. Again, the pattern lines are almost the same.

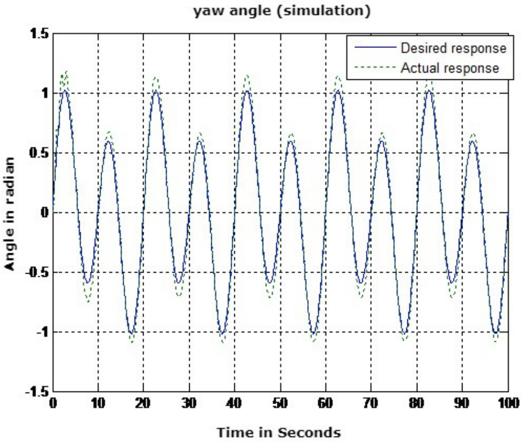

Fig. 9. Yaw rotor responses.

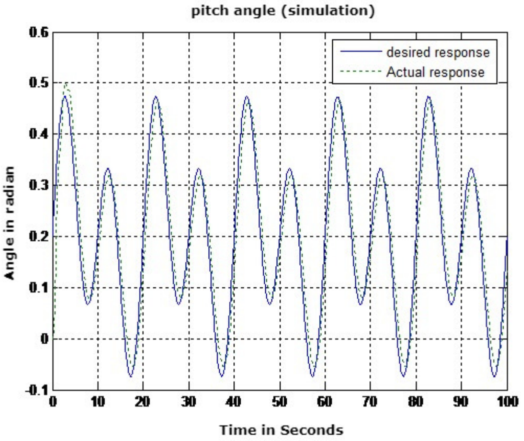

Fig. 10. Pitch rotor responses.

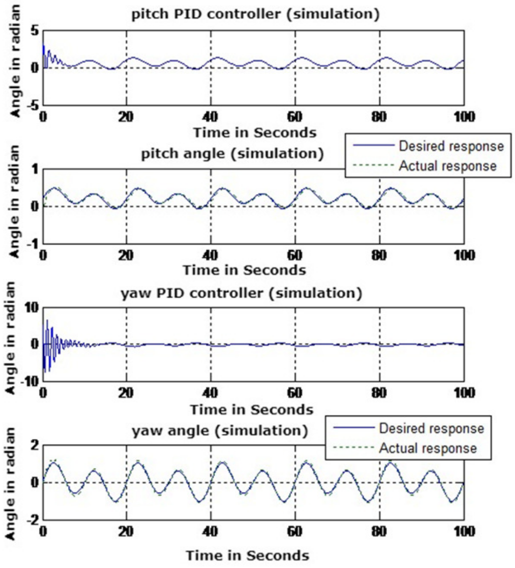

Fig. 11. Simulation results of yaw and pitch rotors with PID controller.

Figures 11 and 12 show the response of the TRMS system. The plot between angle in radians and during 0-100s describes the behavior of the pitch angle response. In both Figures, the plot shows that the desired and the actual results do not have much difference. So, the controller results are considered satisfactory.

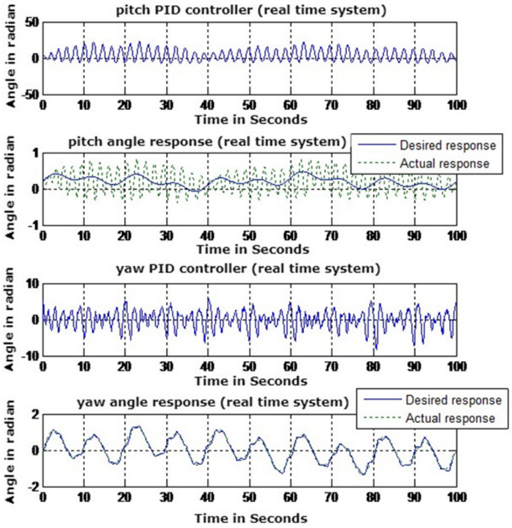

Fig. 12. Real time results of yaw and pitch rotors with PID controller.

V. CONCLUSION

This paper presents a MIMO PID controller designed for a twin rotor system. A non-linear system based design with two inputs and outputs accurately tracks the errors. The performance indices of the simulation results are satisfying and the design simplicity of the control is a major advantage. Both loops are efficiently controlled by the controller without having any process interactions. The steady-state and the transient performance of the proposed controller are satisfactory. The yaw and pitch rotor's real time responses are almost the same.

REFERENCES

[1] N. A. Stanton, K. L. Plant, A. P. Roberts, C. Harvey, and T. G. Thomas, "Extending helicopter operations to meet future integrated transportation needs," *Applied Ergonomics*, vol. 53, pp. 364–373, Mar. 2016, https://doi.org/10.1016/j.apergo.2015.07.001.

[2] J.-G. Juang, R.-W. Lin, and W.-K. Liu, "Comparison of classical control and intelligent control for a MIMO system," *Applied Mathematics and Computation*, vol. 205, no. 2, pp. 778–791, Nov. 2008, https://doi.org/10.1016/j.amc.2008.05.061.

[3] J.-G. Juang, W.-K. Liu, and R.-W. Lin, "A hybrid intelligent controller for a twin rotor MIMO system and its hardware implementation," *ISA Transactions*, vol. 50, no. 4, pp. 609–619, Oct. 2011, https://doi.org/10.1016/j.isatra.2011.06.006.

[4] H. Prabha and R. Kumar, "Real Time Experimental control and Design of FOPIλ and L-PID Controllers tuned by Invasiveweed optimization for Trajectory Control of TRAS," in *2020 International Conference on Power Electronics IoT Applications in Renewable Energy and its Control (PARC)*, Mathura, Uttar Pradesh, India, Feb. 2020, pp. 148–152, https://doi.org/10.1109/PARC49193.2020.236577.

[5] P. Bulucu, M. U. Soydemir, S. Şahin, A. Kocaoğlu, and C. Güzeliş, "Learning Stable Robust Adaptive NARMA Controller for UAV and Its Application to Twin Rotor MIMO Systems," *Neural Processing Letters*, vol. 52, no. 1, pp. 353–383, Aug. 2020, https://doi.org/10.1007/s11063-020-10265-0.

[6] G. Kavuran, B. B. Alagoz, A. Ates, and C. Yeroglu, "Implementation of Model Reference Adaptive Controller with Fractional Order Adjustment Rules for Coaxial Rotor Control Test System," *Balkan Journal of Electrical and Computer Engineering*, vol. 4, no. 2, pp. 84–88, Sep. 2016.

[7] G. Shivani, A. Jamodkar, and J. Pandian B. M. E., "Modeling and Implementation of Adaptive Control Technique on a TRMS Model," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 8, pp. 1015–1020, Jun. 2019.

[8] O. Castillo, F. Kutlu, and Ö. Atan, "Intuitionistic fuzzy control of twin rotor multiple input multiple output systems," *Journal of Intelligent & Fuzzy Systems*, vol. 38, no. 1, pp. 821–833, Jan. 2020, https://doi.org/10.3233/JIFS-179451.

[9] S. Zeghlache and N. Amardjia, "Real time implementation of non linear observer-based fuzzy sliding mode controller for a twin rotor multi-input multi-output system (TRMS)," *Optik*, vol. 156, pp. 391–407, Mar. 2018, https://doi.org/10.1016/j.ijleo.2017.11.053.

[10] Y. Liu, S. Xu, S. Hashimoto, and T. Kawaguchi, "A Reference-Model-Based Neural Network Control Method for Multi-Input Multi-Output Temperature Control System," *Processes*, vol. 8, no. 11, Nov. 2020, Art. no. 1365, https://doi.org/10.3390/pr8111365.

[11] R. Maiti, K. D. Sharma, and G. Sarkar, "PSO based parameter estimation and PID controller tuning for 2-DOF nonlinear twin rotor MIMO system," *International Journal of Automation and Control*, vol. 12, no. 4, 2018, Art. no. 582, https://doi.org/10.1504/IJAAC.2018.095109.

[12] A. Saha and S. Chakraborty, "Genetic algorithm based I-PD controller design for Twin Rotor MIMO system," in *2016 2nd International Conference on Control, Instrumentation, Energy Communication (CIEC)*, Kolkata, India, Jan. 2016, pp. 15–19, https://doi.org/10.1109/CIEC.2016.7513826.

[13] A. Jafar, A. I. Bhatti, S. M. Ahmad, and N. Ahmed, "H∞Optimization-based robust decoupling control algorithm in linear parameter varying systems using Hadamard weighting," *Transactions of the Institute of Measurement and Control*, vol. 41, no. 7, pp. 1833–1848, Apr. 2019, https://doi.org/10.1177/0142331218788121.

[14] H. Bassi and Y. A. Mobarak, "State-Space Modeling and Performance Analysis of Variable-Speed Wind Turbine Based on a Model Predictive Control Approach," *Engineering, Technology & Applied Science Research*, vol. 7, no. 2, pp. 1436–1443, Apr. 2017, https://doi.org/10.48084/etasr.1015.

[15] S. Babesse, "Design of Two Optimized Controllers of a Hydraulic Actuator Semi-Active Suspension: A Comparison Study," *Engineering, Technology & Applied Science Research*, vol. 9, no. 4, pp. 4561–4565, Aug. 2019, https://doi.org/10.48084/etasr.2836.

[16] S. Khandelwal and K. P. Detroja, "The optimal detuning approach based centralized control design for MIMO processes," *Journal of Process Control*, vol. 96, pp. 23–36, Dec. 2020, https://doi.org/10.1016/j.jprocont.2020.10.006.

[17] E. C. goud, S. Rao A., and M. Chidambaram, "Improved Decentralized PID Controller design for MIMO Processes," *IFAC-PapersOnLine*, vol. 53, no. 1, pp. 153–158, Jan. 2020, https://doi.org/10.1016/j.ifacol.2020.06.026.

[18] S. K. Pandey, J. Dey, and S. Banerjee, "Design and real-time implementation of robust PID controller for Twin Rotor MIMO System (TRMS) based on Kharitonov's theorem," in *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Delhi, India, Jul. 2016, pp. 1–6, https://doi.org/10.1109/ICPEICES.2016.7853106.

[19] N. M. H. Norsahperi and K. A. Danapalasingam, "Particle swarm-based and neuro-based FOPID controllers for a Twin Rotor System with improved tracking performance and energy reduction," *ISA Transactions*, vol. 102, pp. 230–244, Jul. 2020, https://doi.org/10.1016/j.isatra.2020.03.001.

[20] R. Maiti, K. D. Sharma, and G. Sarkar, "Adaptive Fuzzy Low-pass Filter Based L1 Adaptive Controller Design for Twin Rotor MIMO System," in *2019 IEEE Region 10 Symposium (TENSYMP)*, Kolkata, India, Jun.

2019, pp. 744–749, https://doi.org/10.1109/TENSYMP46218.2019.8971315.

[21] A. Tastemirov, A. Lecchini-Visintini, and R. M. Morales-Viviescas, "Complete dynamic model of the Twin Rotor MIMO System (TRMS) with experimental validation," *Control Engineering Practice*, vol. 66, pp. 89–98, Sep. 2017, https://doi.org/10.1016/j.conengprac.2017.06.009.

[22] X. Yang, J. Cui, D. Lao, D. Li, and J. Chen, "Input Shaping enhanced Active Disturbance Rejection Control for a twin rotor multi-input multi-output system (TRMS)," *ISA Transactions*, vol. 62, pp. 287–298, May 2016, https://doi.org/10.1016/j.isatra.2016.02.001.