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Fractional Order PID Control for a State Feedback Decoupled Two Input Two Output System

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Abstract

A twin rotor multi-input multi-output system (TRMS) is a nonlinear system with cross couplings between two inputs and two outputs. TRMS has been studied heavily in research as a benchmark for evaluation of control algorithms. In this paper, a state feedback decoupler is developed for the TRMS and investigated against a simplified decoupling approach. Then, a fractional order PID (FOPID) controller is designed for the decoupled TRMS. FOPID controller parameters were determined by applying Simulated annealing (SA) heuristic optimization algorithm in order to find the optimal controller parameters. The main goal of a decoupler is to guarantee time response specifications and eliminate cross-coupling interactions. The state feedback decoupler and their controllers are applied in the process simulation, and the outputs are examined. The overall control structure of the FOPID with the state feedback decoupler is evaluated and assessed for various reference commands to exhibit the applicability of the developed approach.

Keywords: State feedback decoupler; Simplified decoupler; FOPID; TRMS

1. Introduction

Multiple inputs and multiple outputs (MIMO) systems are widely utilized in industry [1]. These systems exhibit cross couplings between inputs and outputs channels making the control problem more challenging. In order to solve this issue, decoupling system techniques are applied. Since the 1960s, decoupling or non-interactive control has drawn a lot of attention for multivariable systems.

The major concept of the decoupling method put out by Boksenbom and Hood is to diagonal the overall closed-loop transfer function of the controlled MIMO system [2] [3]. So, this is only the initial step towards solving the coupling problem. Based on this concept, some other important contributions have been given. For example, Mesarovic [4] used the system transfer function to categories-controlled systems with equal inputs and outputs into the P-canonical and V-canonical system types. A state space method of decoupling control was introduced by Sonquist and Morgan in [5]. Based on state space, Falb and Wolovich [6] created a necessary and sufficient condition for the solvability of the square system decoupling problem. Gilbert then created the equivalent condition for the transfer function represented system [7].

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Gilbert gave a canonical form of the integrator decoupled system results. In comparison to Falb's approach, Gilbert's canonical representation is clear and simple. Moness and Lantos [8] dealt with the problem of designing a pre-compensator, by applying the frequency domain method, Consider the case of a linear system with weak inherent coupling, so that the system would be decouplable via linear state variable feedback alone (LSVF). They presented three algorithms. The first one makes use of a new theorem for dynamic decoupling through LSVF alone, while the other two algorithms make utilize of the interactor concept. Moness and Amin [9] used state space parameters a minimal- order pre-compensator and a static feedback pair are computed as a decoupler. However, the controlled system is assumed to be square in these methods. Wonham and Morse [10] suggested a general decoupling strategy based on a geometric strategy. Silverman [11] created a similar control strategy. Additional decoupling algorithm-related studies are available in [12] [13] [14]. Decoupling approaches for distillation columns areas are widely studied in [15] [16].

There are static and dynamic types of the classical decoupler described in literature. A static decoupler is straightforward to implement as it consists of a gain matrix. The interaction is reduced only in steady state, as opposed to dynamic decoupler. The dynamic decoupler have several architecture such as ideal, simplified, and inverted decoupler [17] [18] [19] [20]. All the decoupler conform to a diagonal transfer function matrix form. However, they have concerns with realizability, complex structures, and sensitivity to modelling errors.

A wealth of research has been carried out on the dynamic state feedback-based decoupled create by (Delin Chu et al [21], Shaohua Tan et.al. [22] and Malabre et.al [23]). There are several methods for getting the set of PD compensators, as mentioned in the literature (Delin Chu et. al [21]). According to Shaohua Tan and Joos Vandewalle [24], proportional and derivative state feedback can enable a decoupling capability that cannot be achieved only by static feedback. Estrada et.al [23] studied the PD state feedback and shown the solutions. Delin Chu [21] applied an orthogonal transformation to solve the PD state feedback decoupling problem.

The twin rotor multi-input multi-output system (TRMS) is a helicopter-like aerodynamic system [25], it is a greatly coupled nonlinear system suggested for the improvement and execution of new control laws [26] [27]. The connected propellers are driven by two direct current rotors on the TRMS. A large propeller powered by the main rotor balances the aircraft on its vertical axis, while a smaller propeller powered by the tail rotor counterbalances the plane on its horizontal axis. The pitch angle and yaw angle, correspondingly, regulate the location of a TRMS on the vertical and horizontal axes [28].

The TRMS is applied for evaluating control algorithms. Due to its cross-coupling and nonlinear structure. Juang et al. [29] utilized a genetic algorithm (GA) to tune a PID controller of TRMS. Classical control methods including Ziegler-Nichols, pole placement, and gain phase margin techniques were used to create TRMS controllers, and they were compared to intelligent control techniques like GA and fuzzy logic [30].

In this paper a fractional order PID (FOPID) controllers are applied to control the decoupled TRMS. This paper is organized as follows. Section 2, the math model of TRMS is discussed. Section 3 shows brief overview of decoupler design. Controller structures and optimization technique operated in are discussed in section 4. Finally, TRMS decoupling control was executed in simulation, and the results were discussed.

2. Mathematical Model of TRMS

TRMS [31] is a lab-scale device that is proposed to be a test platform to understand basic flight dynamics and develop control strategies for vehicles that are similar to helicopter systems. It exhibits the principles of nonlinear MIMO system with significant cross-coupling between vertical and horizontal axes. As shown in Figure 1, the system is controlled by a PC digital controller connected via an I/O data acquisition card.

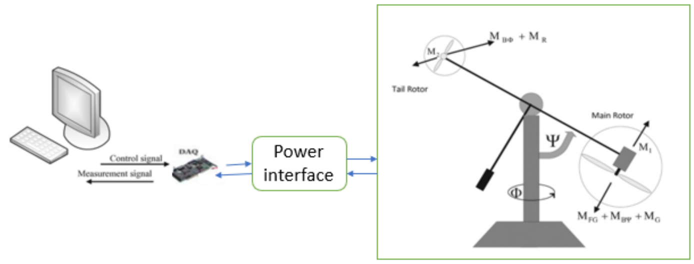

Figure 1: TRMS simplified system schematic

As illustrated in Figure 1, the TRMS contains main rotor and tail rotor which are attached to beam with a counter balance. The beam can rotate in the vertical plane because the main rotor generates a lifting force (pitch). The beam rotates horizontally as a result of the tail rotor in a similar way (yaw). By varying the input voltages to the motors that power the main and tail rotors, respectively, the pitch and yaw angles can be controlled. To measure the pitch and yaw angles, two position sensors are connected to the pivot. The physical system can be controlled through an interface data acquisition card to a MATLAB-Simulink environment.

The dynamic cross-coupling between the rotors is one of the TRMS's key features. Figure 2 displays the block diagram of the TRMS. TRMS have two inputs, [u1, u2] and two outputs [ψ, φ]. Two transfer function models for pitch and yaw motion channels, as well as two transfer function models for cross-coupling paths, are defined, as illustrated in the TRMS block diagram. The dynamic paths in the TRMS system need to be separated, so decoupling functions must be presented [32].

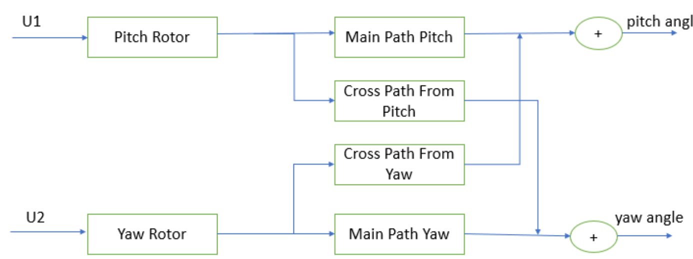

Figure 2: Block diagram for TRMS [32]

The mathematical model of TRMS considered in this paper has been adopted from Tarek [33]. The mathematical model of the pitch motion path is obtained [33] as in equation 1.

$$G_{11} = \frac{0.5318}{0.1905\, s^3 + 0.2679\, s^2 + 0.8833\, s + 1} \quad (1)$$

Also, the mathematical model of the yaw motion path is obtained [33] as in equation 2.

$$G_{22} = \frac{12.0614}{8.4992\, s^3 + 16.1964\, s^2 + 12.9077\, s + 1} \quad (2)$$

For TRMS, Equation 3 is used to obtain the mathematical model of the pitch cross path [33], and equation 4 is used to obtain the mathematical model of the yaw cross path [33].

$$G_{12} = \frac{2.0299}{2.1849\, s^3 + 3.7349\, s^2 + 6.8563\, s + 1} \quad (3)$$

$$G_{21} = \frac{-0.0520}{0.8968\, s^3 + 0.6068\, s^2 + 4.6951\, s + 1} \quad (4)$$

The equivalent system has the following transfer function matrix:

$$G(s) = \begin{bmatrix} \frac{0.5318}{0.1905\, s^3+0.2679\, s^2+0.8833\, s+1} & \frac{2.0299}{2.1849\, s^3+3.7349\, s^2+6.8563\, s+1} \\ \frac{-0.0520}{0.8968\, s^3+0.6068\, s^2+4.6951\, s+1} & \frac{12.0614}{8.4992\, s^3+16.1964\, s^2+12.9077\, s+1} \end{bmatrix} \quad (5)$$

The general state-space representation can be expressed as follows using previous equations:

$$\dot{x} = A\, x(t) + B\, u(t) \quad (6)$$

$$Y(t) = C\, x(t) \quad (7)$$

where x(t) relates to the system states and u(t) the motors inputs, A, B, C is defined by

$$A = \begin{bmatrix} -1.406 & -2.318 & -1.312 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.6766 & -2.618 & -0.5575 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1.709 & -1.569 & -0.4577 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1.906 & -1.519 & -0.4706 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.25 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0.125 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \\ 0 & 2 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 0 & 0.6979 & 0 & 0 & 0 & 0 & 0 & 0.9291 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -0.2319 & 0 & 0 & 0 & 0 & 0 & 2.838 \end{bmatrix}$$

3. DECOUPLING CONTROLLER DESIGN

3.1 State Feedback Decoupling

The transfer function matrix in decoupled systems should have a diagonal form. A decoupled system's standard transfer function matrix can be expressed as:

$$G_d(s) = \begin{bmatrix} g_{1,1}(s) & 0 & \dots & 0 \\ 0 & g_{2,2}(s) & \dots & 0 \\ 0 & 0 & \dots & g_{m,m}(s) \end{bmatrix} \quad (8)$$

Consider a process with m inputs and m outputs that is represented by the state space model (A, B, C, D). If the control signal u is created by state feedback such that

$$U(t) = -Kx(t) + F\, r(t) \quad (9)$$

Where y(t), u(t), and r(t) are real m- vectors, x(t) is a real n-vector and A, B, C, K, and F are real constant matrices of appropriate size. The closed loop transfer function matrix can be written as [9]:

$$G(s) = [(C - DK)(sI - A + BK)^{-1}B + D]F \quad (10)$$

Defining the order d_j for each j, j=1, 2… m, such that it is the lowest order which makes $C_j^T A^i B \neq 0, i = 0,1,\dots,n-1, and\ C_j^T$ is the j[th] row of matrix C.

If the m*m matrix

$$B^* = \begin{bmatrix} C_1^T A^{d_1} B \\ C_2^T A^{d_2} B \\ \vdots \\ C_m^T A^{d_m} B \end{bmatrix} \quad (11)$$

is nonsingular [34], the closed loop system stated in equation (10) can be dynamically decoupled if the state feedback matrix K can be established [35] as

$$C^* = \begin{bmatrix} C_1^T A^{d_1+1} \\ C_2^T A^{d_2+1} \\ \vdots \\ C_m^T A^{d_m+1} \end{bmatrix} F \quad (12)$$

Where, $F = (B^*)^{-1}$

It is possible to completely decouple the square multivariable system by adding the state feedback K and pre-compensator F. Typically, the decoupled transfer function matrix is given by

$$G_d(s) = diag\{ s^{-(d_1+1)}, s^{-(d_2+1)}, \dots, s^{-(d_m+1)}\}$$
(13)

The full feedback control structure can be built by adding the decoupling compensator(K,F), as illustrated in Figure 3. Since the control system may be completely decoupled, it is simple to construct the controller for the system on the basis of each individual loop.

According to TRMS (two inputs two outputs) is described in equation (5), so matrices F and K are given by

$$F = \begin{bmatrix} 0.3534 & -0.2314 \\ 0.0144 & 0.6952 \end{bmatrix} \tag{14}$$

$$K = \begin{bmatrix} 1.3874 & 2.2873 & 1.2947 & 0.0726 & 0.2809 & 0.0598 & \cdots \\ 0.0567 & 0.0935 & 0.0529 & -0.2182 & -0.8442 & -0.1798 & \ldots \end{bmatrix}$$

$$\begin{matrix} 0.5613 & 0.5152 & 0.1503 & -0.3128 & -0.2493 & -0.0773 \\ 0.0229 & 0.0210 & 0.0061 & 0.9400 & 0.7492 & 0.2322 \end{matrix}\Bigg] \tag{15}$$

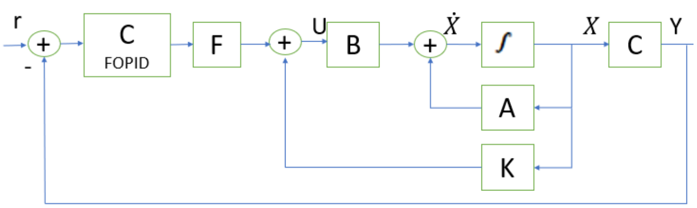

Figure 3: Block diagram of state feedback decoupling method

3.2 Simplified Decoupling

Generally, ideal decoupling, simplified decoupling, and inverted decoupling are the three types of dynamic decoupling algorithms that have received extensive study and are used in industrial operations [36]. Simplified decoupling scheme, proposed by Luyben [37] is straightforward to be applied in practice [38]. It is more often used in literary works. Figure 4 illustrates a typical expression of a simplified decoupled system.

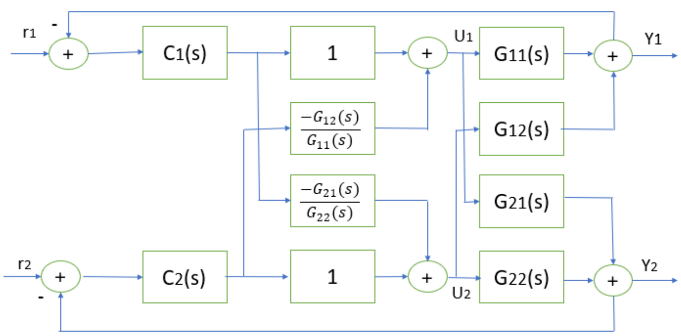

Figure 4: Simplified decoupling structure.

Let consider the following,

$$G(s) = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} \tag{16}$$

$$D(s) = \begin{bmatrix} D_{11}(s) & D_{12}(s) \\ D_{21}(s) & D_{22}(s) \end{bmatrix} \tag{17}$$

And

$$T(s) = \begin{bmatrix} T_1(s) & 0 \\ 0 & T_2(s) \end{bmatrix} = G(s)D(s) \tag{18}$$

$$D(s) = G(s)^{-1}T(s)$$

$$= \frac{1}{G_{11}(s)G_{22}(s)-G_{12}(s)G_{21}(s)} \begin{bmatrix} G_{22}(s)T_1(s) & -G_{12}(s)T_2(s) \\ -G_{21}(s)T_1(s) & G_{11}(s)T_2(s) \end{bmatrix} \tag{19}$$

The only elements that are unknown are T1(s) and T2(s). They represent the desired decoupled system dynamics. The decoupled is determined using the following criteria for the simplified decoupling.

$$D(s) = \begin{bmatrix} 1 & -\dfrac{G_{12}(s)}{G_{11}(s)} \\ -\dfrac{G_{21}(s)}{G_{22}(s)} & 1 \end{bmatrix} \tag{20}$$

By using (16), (18), and (20), As a result, the transfer matrix is represented by:

$$T(s) = \begin{bmatrix} G_{11}(s) - \dfrac{G_{12}(s)G_{21}(s)}{G_{22}(s)} & 0 \\ 0 & G_{22}(s) - \dfrac{G_{12}(s)G_{21}(s)}{G_{11}(s)} \end{bmatrix} \tag{21}$$

Where,

$$T_1(s) = G_{11}(s) - \frac{G_{12}(s)G_{21}(s)}{G_{22}(s)} \tag{22}$$

And,

$$T_2(s) = G_{22}(s) - \frac{G_{12}(s)G_{21}(s)}{G_{11}(s)} \tag{23}$$

Waller et al. [39] presented three different configurations of simplified decoupling taking into account the realizability problems. It is possible to put two items from various columns of matrix D(s) into 1. Thus, the three other simplified decoupling configurations are as follows:

$$D(s) = \begin{bmatrix} -\dfrac{G_{22}(s)}{G_{21}(s)} & 1 \\ 1 & -\dfrac{G_{11}(s)}{G_{12}(s)} \end{bmatrix} \tag{24}$$

$$D(s) = \begin{bmatrix} -\dfrac{G_{22}(s)}{G_{21}(s)} & -\dfrac{G_{12}(s)}{G_{11}(s)} \\ 1 & 1 \end{bmatrix} \tag{25}$$

$$D(s) = \begin{bmatrix} 1 & 1 \\ -\dfrac{G_{21}(s)}{G_{22}(s)} & -\dfrac{G_{11}(s)}{G_{12}(s)} \end{bmatrix} \tag{26}$$

There must be two functions in this case if there are two main paths and two cross-coupling paths, as in TRMS [38]. Transfer functions that represent the decoupling are calculated according to equation 5 (that showed transfer function for TRMS), and equation 22,23, So, the D(s) will give as the following:

d11=d22=1

$$d_{12} = \frac{-0.3867s^3 - 0.5438\,s^2 - 1.793\,s - 2.03}{1.162\,s^3 + 1.986 * s^2 + 3.646\,s + 0.5318}$$

$$d_{21} = \frac{0.442\,s^3 + 0.8422\,s^2 + 0.6712\,s \mp 0.052}{10.82\,s^3 + 7.319\,s^2 + 56.63\,s + 12.06}$$

4. Controller Design

4.1. Fractional Order PID Controller Structure

To control the TRMS, a variety of control strategies and algorithms have been investigated. PID controllers are among of the most widely used in the industry [40]. Equation 27 illustrates how the PID controller's transfer function works.

$$C(s) = K_p + \frac{K_i}{s} + K_d s \qquad (27)$$

Where, K_p is the coefficient of the proportional term, K_i is the coefficient of the integral term, and K_d is the coefficient of the derivative term.

The idea of Fractional Order of PID [FOPID] controllers was offered by Podlubny in 1997 [41]. Also, he showed that when applied for the control of fractional order systems, these controllers achieve better response than traditional PID controllers. When compared to integer order PID, the FOPID has two more parameters. Where the derivative term's degree is μ and the integral term's degree is λ. Equation 28 displays the FOPID controller's equation [42].

$$C(s) = K_p + \frac{K_i}{s^{\lambda}} + K_d s^{\mu} \qquad (28)$$

In the majority of cases, the FOPID controller implements more effectively than a traditional PID controller whereas the performance of a normal PID controller degrades in higher order systems. In systems with a long-time delay, the FOPID controller operates more effectively. Notably, the FOPID controller performs better performance in criteria like stability and robustness. Traditional PID controllers make it difficult to control nonlinear systems, whereas FOPID controllers can control them [43]. In this study, the FOPID controller was used because of the nonlinear character of the TRMS system.

4.2. Optimization Method

Figure 5 displays the design of the model utilized to determine the controller parameters. To converge the error to zero in the optimization approaches, a fitness function should be used. Because of this, integral performance standards may be applied. For this study, the ITSE integral performance criterion was chosen. Equation 29 represents the ITSE criterion [44].

$$J = \int_0^{\infty} t.e^2(t)dt \qquad (29)$$

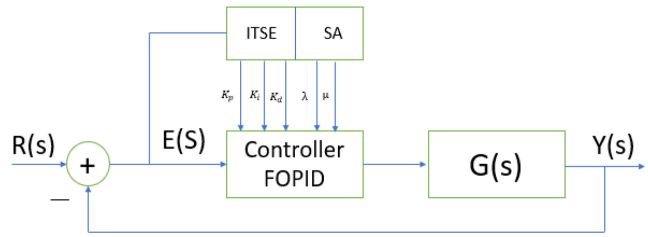

Figure 5: Block diagram of the optimization process's feedback control system

Simulated annealing [SA], presented by Metropolis in 1953 [45], uses heuristics to approximately optimize globally over a large search space [46]. This optimization technique can be used in problem spaces and random searches. It was enhanced and improved by Kirkpatrick et al. in 1983 [47] and Cerny in 1985 [48] to apply the general SA algorithm.

Simulated annealing just needs one initial subject as a starting point and follows to a set of rules that contains the particle's random behavior during the annealing process. Because of this, it is a method that occasionally permits a move that involves climbing a hill to avoid becoming trapped in local optima. A random number generator and a control parameter called temperature are used to do this. The temperature parameter separates the objective function's major and small changes. Large changes occur at high temperatures while smaller changes occur at low temperatures. As the algorithm executes, the temperature progressively drops from its high starting point. The algorithms agree that the solutions that are worse than our current solution exist while the temperature variable is high. Because of this, the algorithm has the possibility of leaving any local optimums it reaches early in execution. After the temperature is lowered, the algorithm periodically focuses on a specific area of the search space in the hopes of finding a solution that is near to the ideal one.

In general, the initial temperature for simulated annealing should be high to allow the algorithm to agree on a poorer solution than the one being used now. In general, the algorithm is more likely to agree on the answer when there is less energy variance (measured as the quality of the solution) and when the temperature is higher. The objective function wants to be assessed, after temperature initialization. A condition that determines if the neighboring solution is superior to the current solution is there after the development of the new solution. The value will be updated as a result if it is better. If it isn't improved, the temperature should be changed and a new set of solutions should be found. The process will be repeated until the best result is obtained. Finally, when the temperature drops, the system decides on the best optimal solution.

5. SIMULATION AND RESULTING

These two methods for decoupling (state feedback decoupled and simplified decoupled) applied on simulation of TRMS according to equation (14). (15), (22), (23). In controller design, the optimal controller parameters are determined using simulated Annealing algorithm. The ITSE performance criterion was used in the optimization procedure to reduce error. The obtained controller for T1(s) is given in Equation (31), and obtained controller for T2(s) is given in Equation (32) for simplified decoupled, and for state feedback decoupled is given in Equations (33,34).

$$C_1(s) = 9.9972 + \frac{9.992}{s^{1.0124}} + 3.1722\, s^{1.6837} \quad (31)$$

$$C_2(s) = 9.9902 + \frac{0.4498}{s^{1.0893}} + 9.9963\, s^{1.5619} \quad (32)$$

$$C_1(s) = 8.229 + \frac{3.3066}{s^{0.0375}} + 35.5584\, s^{1.7475} \quad (33)$$

$$C_2(s) = 0.0433 + \frac{0.0403}{s^{0.1712}} + 18.3441\, s^{1.8394} \quad (34)$$

In the Simulink model displayed in Figure 6 and Figure 7. The FOPID controller blocks were set and the resulting controller parameters are simulated for 100 sec. Figure 8 displays the unit step responses of the systems that were under the control of the resulting fractional order controller using state feedback decoupling.

Step pitch input is applied and the reference yaw input is zero in order to first confirm the decoupling between the reference pitch input and yaw output. Under this situation the outputs obtained are presented in Figure 9. Its cases illustrate that the yaw output is shifting very slightly, as expected, in response to variations in pitch input. After that, to confirm the separation of reference yaw input and pitch output, step yaw input is applied and the reference pitch input is zero. Figure 10 illustrates the response obtained under these conditions and shows how, as would be expected, the pitch output varies very little as a result of variations in the yaw input.

It is shown in Figure 11, Figure 12 and Table 1, that results obtained using state feedback decoupling controller in the Simulink model were compared with the results obtained using simplified decoupling controller. In state feedback decoupling method rise time and settling time is reduced more than simplified decoupling method. it is shown in Table 1. It is clearly seen that the state feedback decoupling controller performs better than the simplified decoupling controller.

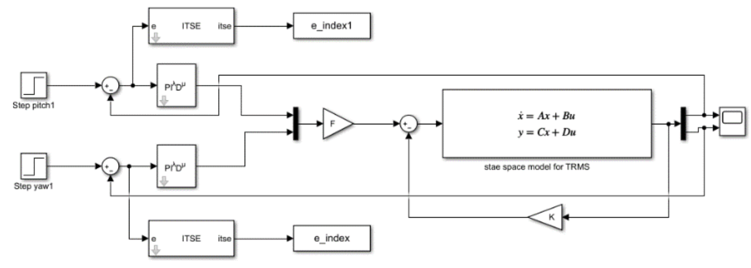

Figure 6: Simulink model of state feedback decoupling control for TRMS

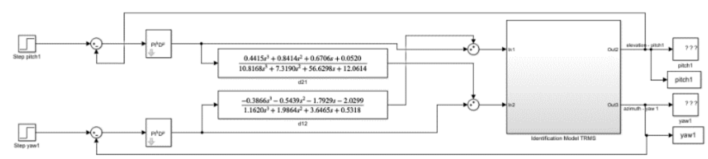

Figure 7: Simulink model of simplified decoupling control for TRMS

Table 1: Performance Criteria of state feedback and simplified decoupled

Type of decoupled	**State feedback decoupled**		**Simplified decoupled**	
	Pitch	Yaw	Pitch	Yaw
Rise time	0.0830	0.1344	0.2944	0.2390
Settling time	0.6281	0.5008	1.3019	3.3530
Over shoot	27.5914	12.0616	5.7630	9.4116
Peak	1.2759	1.1206	1.0576	1.0941
Peak time	0.2000	0.2000	0.6	0.5

6. CONCLUSION

This study investigates and presents the controller design for decoupled MIMO systems. This controller's primary goal is to guarantee time response specifications and remove interaction of cross-couplings. Multivariable systems have been decoupled using two different decoupling techniques. The results of the simulation show that it is possible to design the proposed controller using one of these techniques. Then, the diagonally-obtained TRMS model is controlled by FOPID. FOPID controller parameters were determined by applying SA heuristic optimization algorithm in order to find the optimal controller parameters. The results taken using state feedback decoupling controller in the Simulink model were compared with the results obtained using simplified decoupling controller. The state feedback decoupling controller performs better than the simplified decoupling controller regarding time response specifications.

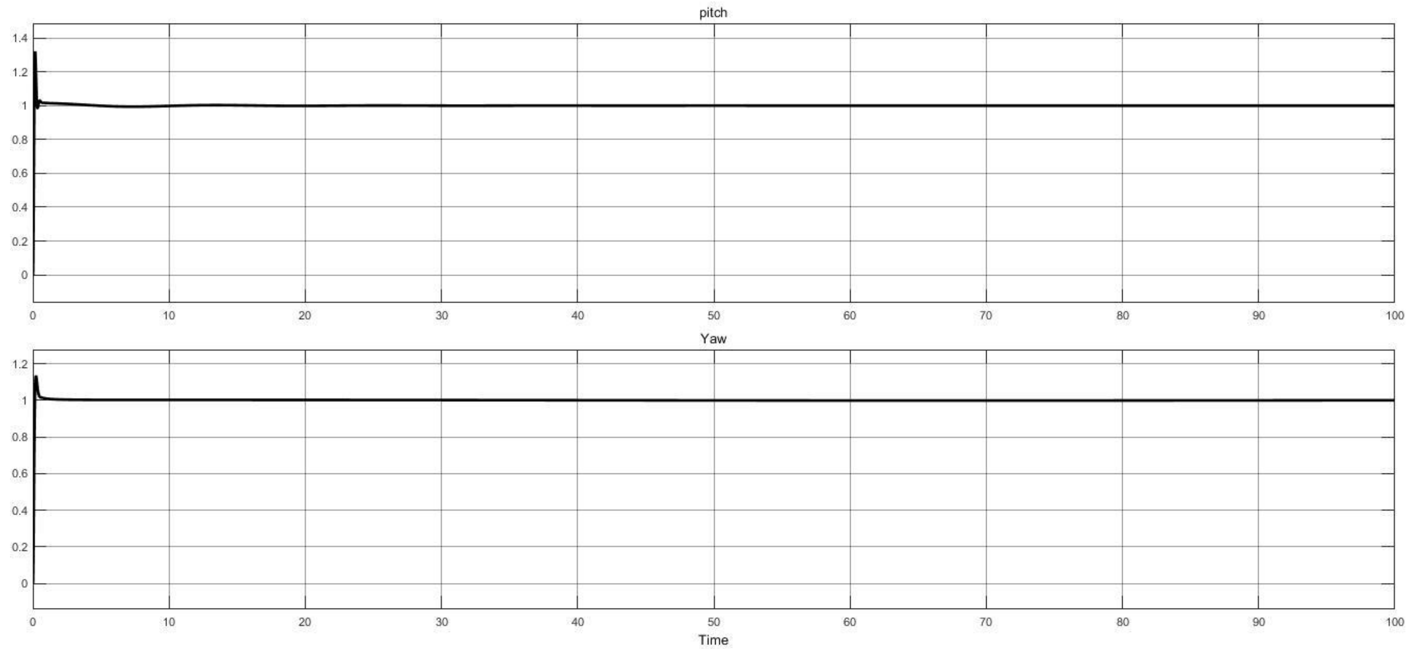

Figure 8: Step response for pitch position and yaw position using state feedback decoupler.

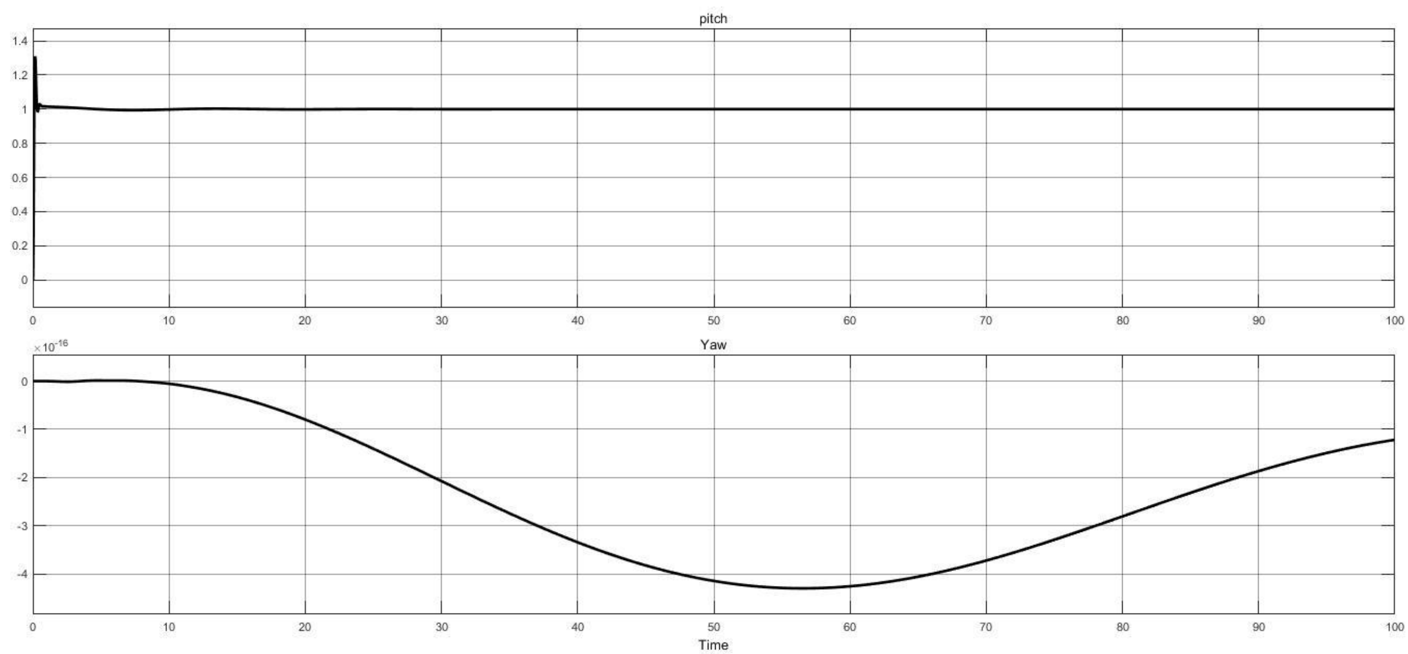

Figure 9: Step response for pitch position and zero input for yaw using state feedback decoupler.

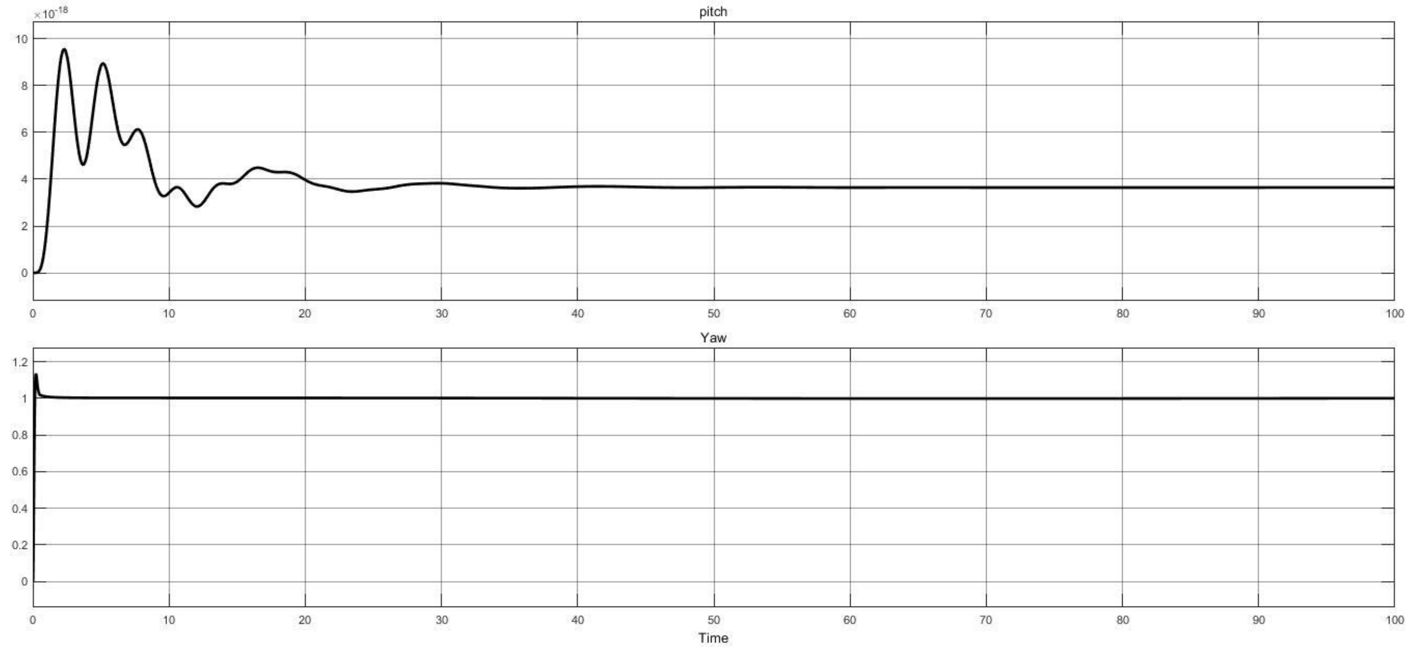

Figure 10: Step response for yaw position and zero input for pitch using state feedback decoupler.

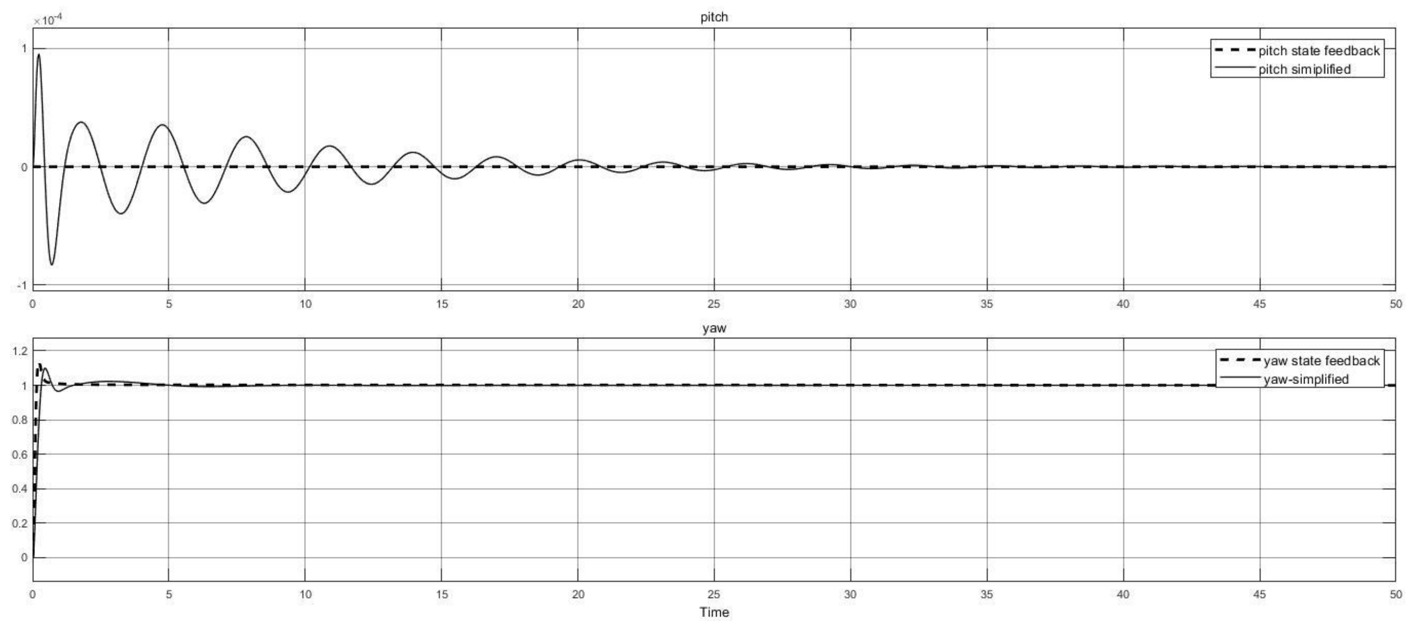

Figure 11: Step response for yaw position and zero input for pitch using state feedback and simplified decoupler

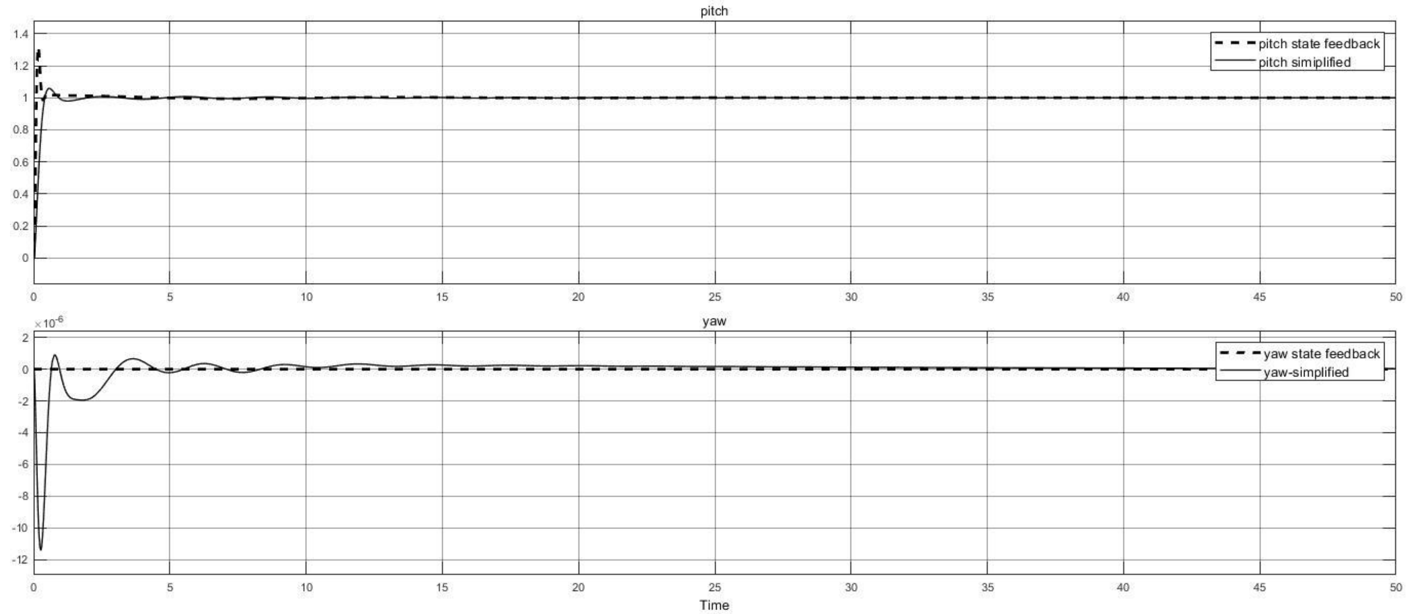

Figure 12: Step response for pitch position and zero input for yaw using state feedback and simplified decoupler

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نظام التحكم التفاضلي التكاملي باستخدام طريقة التغذية العكسية للحالة لنظام ثنائي المدخلات وثنائي المخرجات

الملخص العربي :

نظام متعدد المخرجات متعدد المدخلات (TRMS) هو نظام غير خطي مع وصلات عرضية بين مدخلين ومخرجين .تمت دراسة TRMS بشكل مكثف في البحث كمعيار لتقييم خوارزميات التحكم . في هذا البحث ، تم تقديم وفحص تصميم وحدة التحكم لأنظمة متعددة المدخلات والمخرجات(MIMO)الهدف الأساسي لوحدة التحكم هذه هو ضمان مواصفات الاستجابة الزمنية وإزالة تفاعل أدوات التوصيل المتقاطعة .تم استخدام طريقتين للفصل لفصل النظام متعدد المتغيرات .تظهر نتائج المحاكاة أنه من الممكن استخدام إحدى هذه الطرق في تصميم وحدة التحكم المقترحة .بعد ذلك ، يتم التحكم في نموذج TRMS بواسطة FOPID. تم تحديد معاملات وحدة تحكم FOPID من خلال تطبيق خوارزمية تحسين الكشف (simulated annealing) من أجل العثور على معاملات وحدة التحكم المثلى .تمت مقارنة النتائج التي تم الحصول عليها باستخدام وحدة تحكم فصل التغذية العكسية للحالة (state feedback decoupler) مع النتائج التي تم الحصول عليها باستخدام وحدة تحكم فصل مبسطة(simplified decoupler) .تعمل وحدة التحكم في فصل التغذية العكسية للحالة (state feedback decoupler) بشكل أفضل من وحدة تحكم الفصل المبسطة (simplified decoupler) فيما يتعلق بمواصفات الاستجابة الزمنية.