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Determining the Parameters of the Controllers of the TRMS System Using the Cuckoo Algorithm

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Abstract – The twin rotor multiple-input multiple output (TRMS) system, which emerged as the prototype of the helicopter, is a non-linear system. It is very difficult to find the controller coefficient in the control of non-linear systems. Apart from classical methods, metaheuristic algorithms based on the behavior of animal herds can be used to find the coefficients of PID and derivative controllers. Metaheuristic algorithms search for coefficients within the lower and upper limits determined by the population created outside of the classical coefficient finding methods. While doing this search, it performs optimization in each iteration. In the search made in iterations, the power and performance of the algorithm is determined by the objective function of that algorithm. The stronger the objective function used, the stronger the coefficients obtained can control the non-linear system. In the study, the coefficients of the PID and modified I-PD controller were found by the Cuckoo algorithm for the two degrees of freedom (2-DOF) pitch and yaw angles in TRMS to reach the reference values. The coefficients found were compared for pitch and yaw angles in TRMS both in terms of linearized transfer functions and on the model based on the physical model of TRMS. As a result, when the overshoot time, settling time and rise times were examined, it was seen that the transfer function model of the TRMS system gave more successful results.

Keywords – TRMS, Pitch And Yaw Angle, Cuckoo Algorithm, Metaheuristic, I-PD Controller

I. Introduction

TRMS is a two input two output system developed for application in control experiments. The system can move in horizontal and vertical planes by means of perpendicular propellers at both ends of the free rod. The propellers are rotated by DC motors. The angles of the system with the horizontal and vertical axis are controlled by the force produced by the propellers [1-3].

Optimization, in general terms, is all of the processes or methods that must be applied to make a system as efficient as possible, within certain constraints, at the least cost. In short, it is the process of optimally solving a problem or optimizing a system as possible.

Today, with the active use of many aircraft, studies on mechanical systems in both small-scale aircraft and helicopters and their derivative aircraft, and studies on the development of technical components in this direction are increasing day by day [4-7]. Dynamic systems of aircraft are difficult to model because of the significant coupling effect between propellers and the inability to find some system states. A robust control method is essential to obtain suitable durability to deal with the uncertainty of model parameters and load disturbances. Especially the balance between the propellers is the most important factor that ensures the existence of the helicopter and flight safety [8-9].

For the control of the propeller angles in the TRMS system, different operating results can be obtained in the PID controller results. In sliding mode controllers, successful results can be seen at any given reference angle [10].

In the studies on TRMS, the mathematical model for the vertical and horizontal movements of the TRMS was obtained on MATLAB in the laboratory environment [11].

In the study on real-time control with the PI-PID controller using particle swarm optimization, a significantly higher performance was observed with the PI-PID controller [12].

The double rotor multiple input multiple output (TRMS) is a system that represents the dynamics of the helicopter. The TRMS system consists of the main and tail propellers connected by a beam. This system is a nonlinear complex system. In order to balance the TRMS system, both propeller angles are made by changing the speeds of the DC motors to which the propellers are connected. There are many control methods for speed control of DC motors. The proportional-integral-derivative (PID) method was used in the study. Determining the controller parameters used in the PID method affects the operation of the system. Many methods such as open-loop Ziegler-Nichols, closed-loop Ziegler-Nichols, Cohen-Coon Tuning Method, trial and error are used for the estimation of controller parameters.

In the study, the controller parameters were estimated using the cuckoo algorithm, which is one of the meta-heuristic optimization algorithms.

The Cuckoo Algorithm is named after one of the birds that exist in nature, the cuckoo. The purpose of this algorithm is based on finding the most suitable nest so that the probability of survival is high by laying eggs in the nests of other bird species. The most important reason that distinguishes the cuckoo from other birds and is the subject of optimization algorithms; aggressive reproduction strategies [13-15].

The simulation studies for estimating the parameters and obtaining the output values of the system were made in the MATLAB/Simulink program. The studies were carried out after finding the controller parameters that best approximate the main and tail propellers to the reference angle value in the simulation studies.

The reason why we use the I-PD controller, which is a modified PID controller, in this System, in addition to the classical controllers, is that this mode facilitates nonlinear systems such as helicopters to be asymptotically stable.

In this study, the reason for estimating the PID and I-PD controller parameters in the TRMS system using the cuckoo algorithm, which is one of the meta-heuristic optimization algorithms, is because we can perform the estimation of the controller parameters in a short time with this algorithm.

II. MATERIALS AND METHOD

The materials and methods used in conducting the study are explained in detail in subsections.

A. Twin Rotor Mimo System(TRMS)

The twin rotor multi-input and multi-output system (TRMS) has been experimentally and simulated, and has been studied as a helicopter prototype in recent years [16]. This system has two different angles, pitch and yaw. Two separate transfer functions have been created for pitch and yaw angles in TRMS, and these transfer functions have been studied. The physical model of TRMS is given in Figure 1.

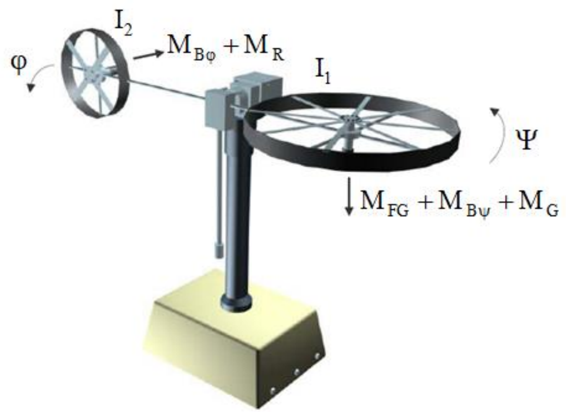


Fig. 1 Physical view of the TRMS system

The transfer functions for the pitch and yaw angles of the TRMS, whose physical model is given in Figure 1, are given in equations 1 and 2.

$$G_{pitch} = \frac{1.359}{s^3+0.997*s^2+4.786*s+4.278} \quad (1)$$

$$G_{yaw} = \frac{3.6}{s^2+5*s+6} \quad (2)$$

B. The Cuckoo Algorithm

The cuckoo search algorithm was designed and developed, inspired by the reproduction strategies of cuckoos. The inspiration for the algorithm is brood parasitism (Yang and Deb, 2009). What distinguishes cuckoos from other birds and is the subject of optimization algorithms; aggressive reproduction strategies [13-15].

The most distinctive feature of cuckoos; laying their eggs in other birds' nests. If the original owner of the nest detects an egg that does not belong to him; either nests in another place or throws the egg that has been laid in its nest.

In order to solve the optimization problem in the cuckoo algorithm, in the first step, the positions of the first population should be known. The first positions mentioned above are kept in an array. This series is referred to as the "raising environment". In an example optimization problem with N dimensions, the available life positions are retained as follows:

$$habitat(n) = [x_1, x_2, \dots, x_N] \quad (3)$$

If this function, chosen as the criterion function, is adapted according to the living space, the cost function:

$$CostFunction = f(habitat) = f(x_1, x_2, \dots, x_N)$$

$$X_i^{(t+1)} = X_i^{(t)} + \alpha . Le'vy(\lambda) \quad (4)$$

$\alpha > 0$ is the step size in the specified problem. $levy(\lambda)$ represents the Lévy flight for both local and global search. The Lévy flight function is produced according to the equation given below.

$$levy(\lambda) = t^{-\lambda}, \qquad (1 < \lambda \leq 3) \quad (5)$$

t is the number of iterations. The algorithm can also be extended to cases where each slot contains a set of solutions [17]. The flowchart of the cuckoo algorithm is given in Figure 2.

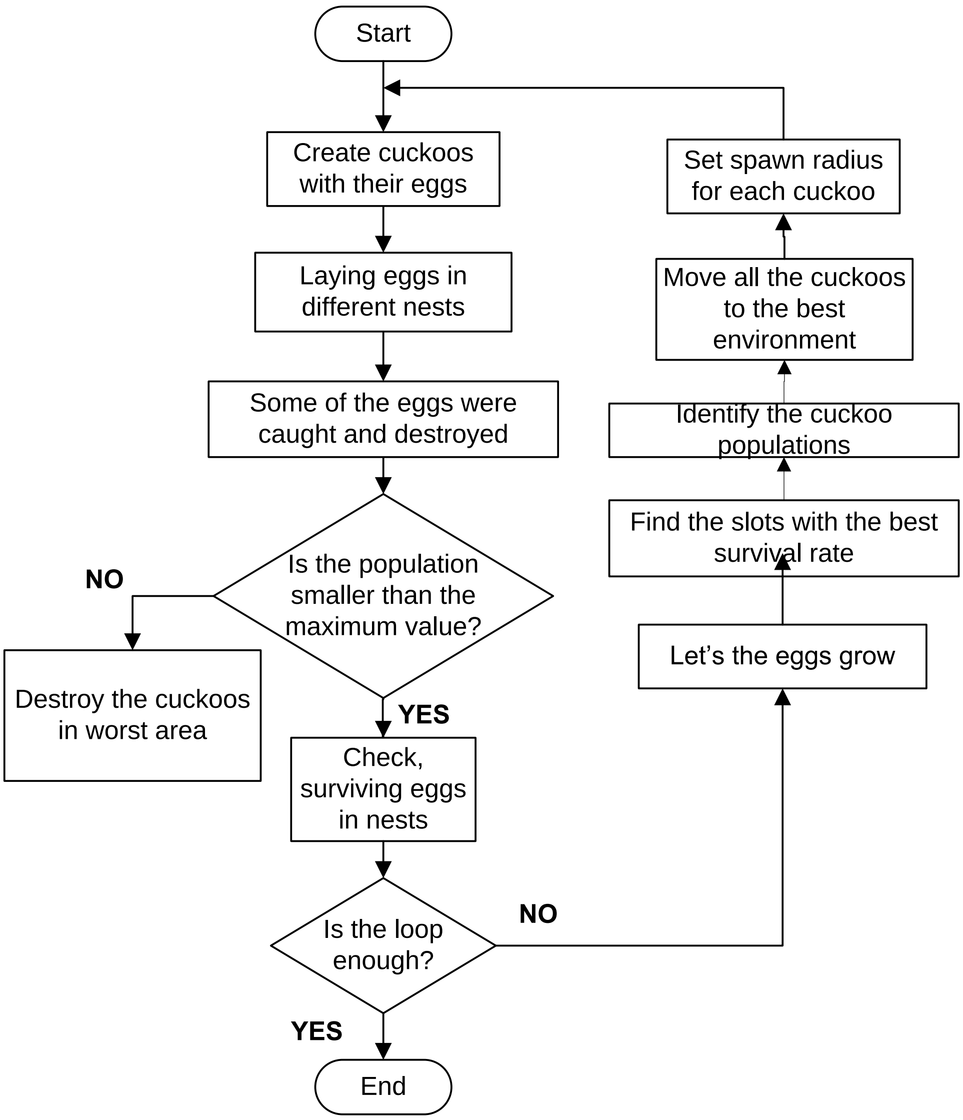
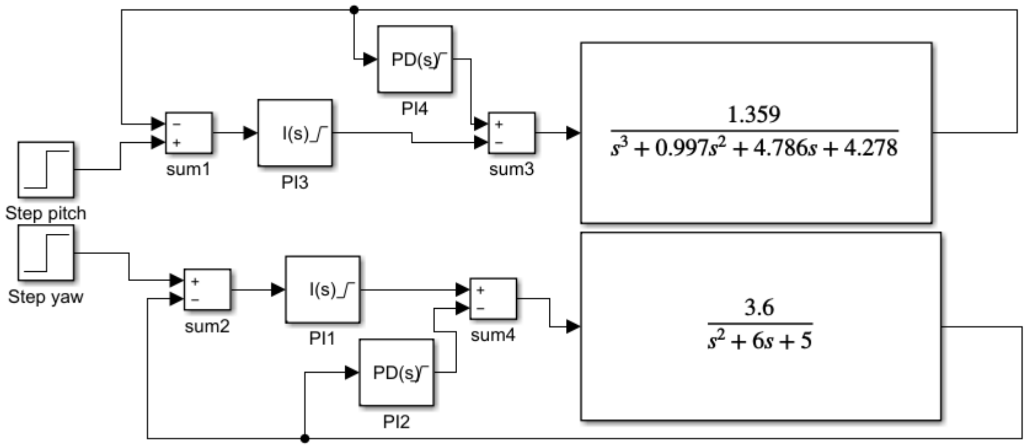
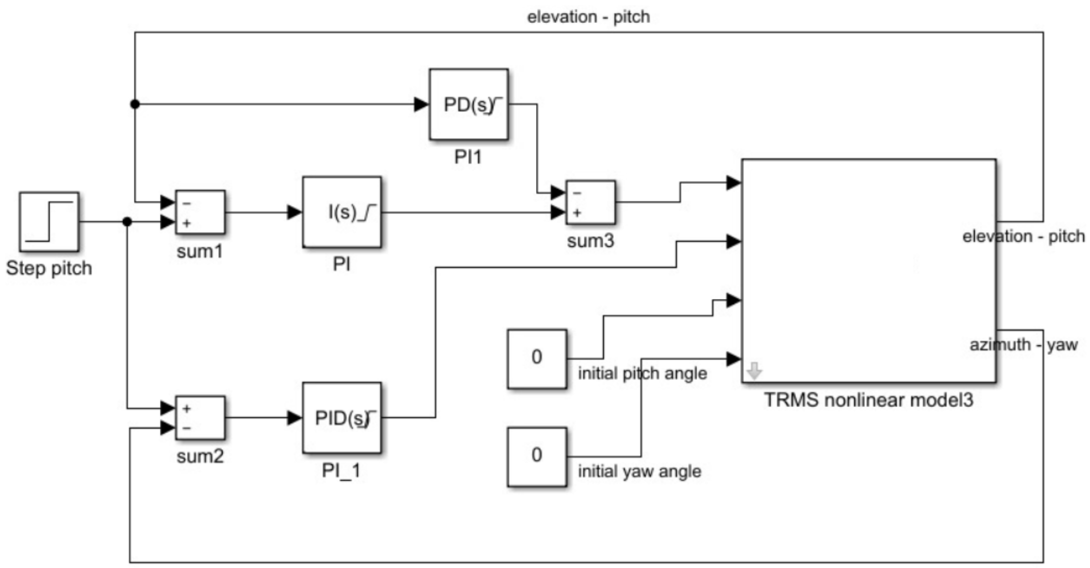


Fig.2 Cuckoo algorithm flowchart [18]

In the study, the general block structures of the system are given in detail in Figures 3a and 3b. Here, the integrated structures of the Simulink and PID controller coefficients are seen. Each structure gives information about the general lines of the system. models created using both the physical model of the TRMS system and the transfer function, with the help of the Cuckoo algorithm, with the I-PD These connections help us better understand the communication between the blocks of the system.



a)



b)

Fig. 3 Block diagrams of different TRMS models used to optimize pitch and yaw angles a) I-PD control model and b) PID control model

III. Results

As a result of the obtained results, it has been observed that the results obtained for the transfer function of TRMS are better than the results obtained for the physical model. This situation was observed more clearly especially in the yaw angle. As can be seen in Figures 4 and 5, using the transfer function with the I-PD controller, it was seen that both the yaw and pitch angle of the TRMS system gave better output responses than the physical model.

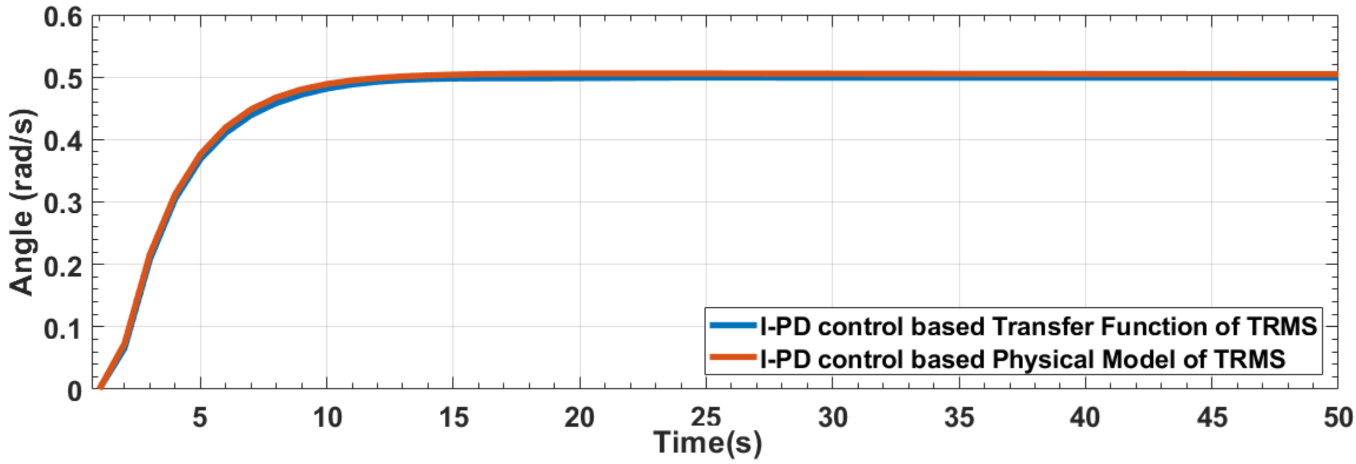


Fig. 4 Effects of pitch angles on different TRMS models with the I-PD controller

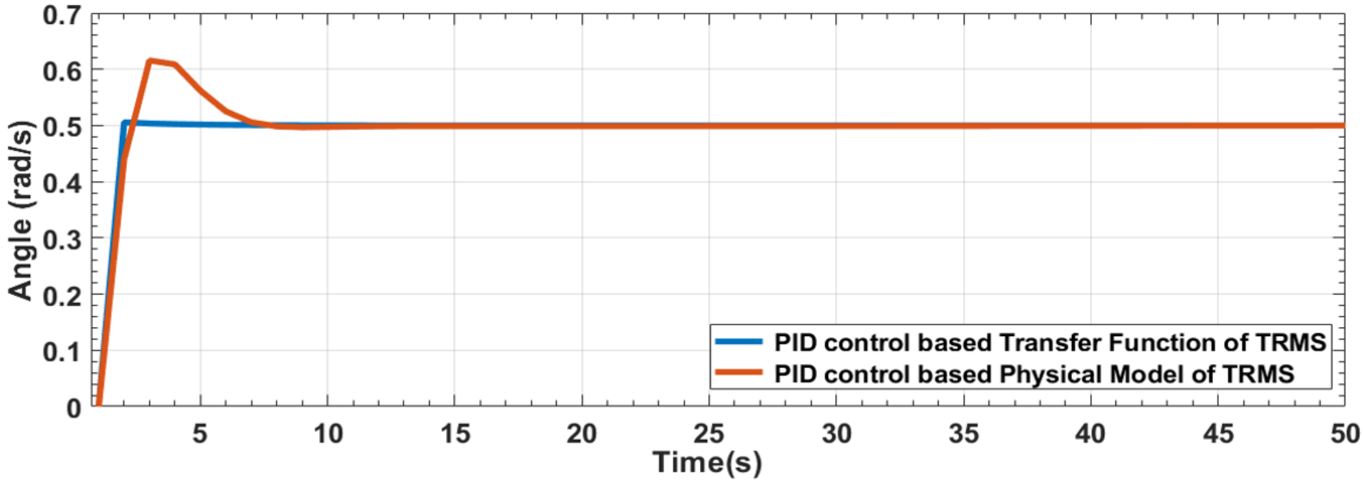


Fig. 5 Effects of yaw angles on different TRMS models with the I-PD controller

The results obtained are given in detail in Tables 1 and 2 in the form of comparative tables. In these tables, important criteria such as settling time, rise time, overshoot time of each angle are calculated one by one. The parameter values used in obtaining these values are given in the rest of the table. It becomes possible to make an inference about the general structure of the system.

Table 1. Output response values of the Cuckoo algorithm on different TRMS dynamic models

Model parameter	**Angle**	**Controller**	**Rise Time**	**Settling Time**	**Overshoot(%)**
Transfer function model	Pitch	I-PD	5.7714	11.227	0.0314
Transfer function model	Yaw	PID	0.7910	1.9689	1.1440
Nonlineer system model	Pitch	I-PD	5.6154	10.965	0.2467
Nonlineer system model	Yaw	PID	0.9404	6.7847	23.15

Table 2. Parameter values obtained with the Cuckoo algorithm for different TRMS dynamic models

Angle	Model parameter	Controller	Kp	Ki	Kd
Pitch	Transfer function model	I-PD	6.8666	7.5055	21
Yaw	Transfer function model	PID	18.4638	6.869	2.3385
Pitch	Nonlineer system model	I-PD	7.4	8.4	20.9
Yaw	Nonlineer system model	PID	34.1227	19.2149	23.2917

A. IAE, ISE, ITAE and ITSE Error Analysis

Specific tests are carried out to examine the fault performance of TRMS. These tests are integral absolute error (IAE), integral squared error (ISE), integral time absolute error (ITAE), and integral time squared error (ITSE). Mathematical expressions of error performance criteria are given as equations [19, 20].

$$ISE = \int_0^\infty e^2(t)dt \quad (6)$$

$$ITSE = \int_0^\infty e^2(t)tdt \quad (7)$$

$$IAE = \int_0^\infty |e(t)|dt \quad (8)$$

$$ITAE = \int_0^\infty t|e(t)|dt \quad (9)$$

The error performances of the Cuckoo algorithm, whose drawings are given in Matlab/Simulink in Figure 3-4, are given in detail in Table 3.

Table 3. Controller error performance analysis of the Cuckoo algorithm

Angle	Model parameter	Controller	ISE	IAE	ITAE	ITSE
Pitch	Transfer function model	I-PD	11.37	23.4	620.1	620.1
Yaw	Transfer function model	PID	0.04	0.13	0.07	0.03
Pitch	Nonlineer system model	I-PD	0.4583	1.66	8.862	1.88
Yaw	Nonlineer system model	PID	0.1419	0.66	1.78	0.82

IV. DISCUSSION

In this study, more optimum results can be obtained by trying different algorithms rather than the Cuckoo algorithm tested on different controllers.

V. CONCLUSION

In the study, yaw and pitch angles were simulated with the Cuckoo algorithm. Considering the overshoot time, settling time and rise times, it was seen that the transfer function model of the TRMS system gave more successful results than the physical model.

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