Real Time Control of Twin Rotor MIMO System using Intelligent Controller

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Abstract— This paper discusses the scope of designing and implementing a intelligent hybrid PID control technique to the Twin Rotor Multi-input multi-output System (TRMS). Control of nonlinear system has always been a challenging problem due severe nonlinearities, inaccessibility of some states and output for measurement with significant cross coupling. The control objective is to make this systems move quickly so that it track the given reference inputs accurately. Real time performance of Twin Rotor Multi-input multi-output System (TRMS) with the intelligent controllers has been shown.

Key words: Hybrid; Neural, fuzzy; Twin Rotor Multi Input Multi Output System (TRMS); Nonlinear

I. INTRODUCTION

Controlling nonlinear systems in real physical systems is a difficult problem due to flexible dynamics. The TRMS is a laboratory set up designed for control experiment. With some significant simplification it serves as a model of helicopter. TRMS is benchmark problem for many important application like control of helicopter.The overall mathematical model is supposed to be needless in this paper with respect to the adjustable parameters of PID controller therefore designed process is brief but comprehensive and therefore controller is assumed to be more robust.

This paper is categorized as follows, Section II consist of introduction to Twin Rotor Multi-input multi-output System (TRMS). Section III deals with the method of designing the intelligent controller. In section IV, the simulation results are presented and last section consists of conclusion.

II. TWIN ROTOR MIMO SYSTEM

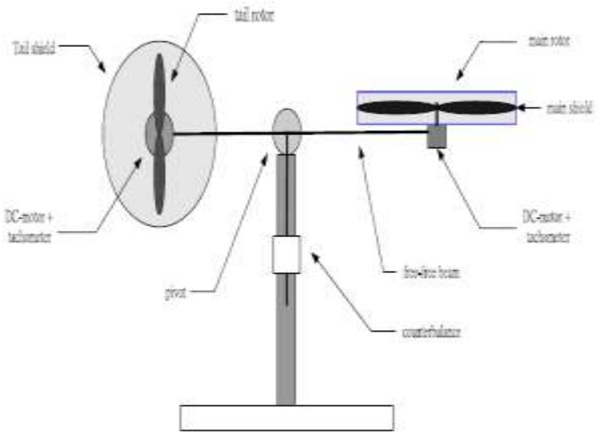


Fig. 1: Twin Rotor MIMO system

The TRMS consist of beam, such that it can rotate freely both in vertical and horizontal planes as it pivoted on its base. Two propellers are present at both ends of the beam perpendicular to each other which are driven by permanent magnet DC motors.

A pendulum counter weight is fixed to beam at the pivot for balancing the angular With two input (the voltage supplied to the motors) and output (angles and angular velocities) the twin rotor multi input multi output system (TRMS) is the excellent multi input multi output plant in which changing the input voltage of these two motors (rotors) i.e. aerodynamic force is controlled.

A change in voltage value results in a change in aerodynamic force which results in a change of corresponding position of beam The TRMS is controlled with two inputs. The dynamics cross couplings are one of the key features of the TRMS. The position of the beams is measured with the means of incremental encoders, which provide a relative position signal. Thus every time the real-time TRMS simulation is run one must remember that setting proper initial conditions is important.

Rotation of the propeller produces an angular momentum, which, according to the law of conservation of angular momentum, must be compensated for by the remaining body of the TRMS beam [6].

The mathematical model of the main rotor,

$$\frac{dS_v}{dt} = l_m S_f F_v(w_m) - \Omega_v k_v + g\left((A-B)\cos\alpha_v - C\sin\alpha_v\right) - \frac{1}{2}\Omega_h^2 k^2 (A+B+C)\sin 2\alpha v \quad (1)$$

$$\frac{d\alpha_v}{dt} = \Omega_v \quad (2)$$

$$\Omega_v = \frac{S_v + J_{tr} w_r}{J_v} \quad (3)$$

$$u_{vv} = \frac{U_v}{T_{mr}s + 1} \quad (4)$$

$$\frac{du_{vv}}{dt} = \frac{1}{T_{mr}}(-u_{vv} + U_v) \quad (5)$$

$$W_m = P_v(u_{vv}) \quad (6)$$

Where,

$$A = \left(\frac{m_t}{2} + m_{tr} + m_{ts}\right) l_t$$

$$B = \left(\frac{m_m}{2} + m_{mr} + m_{ms}\right) l_m$$

$$c = \left(\frac{m_b}{2} l_b + m_{cb} l_{cb}\right)$$

α_v,α_v Horizontal and vertical position of TRMS beam,

Ω_h, Ω_v Horizontal and vertical angular velocity of TRMS beam,

U_h, U_v Horizontal and vertical DC motor voltage control input,

P_h, P_v Nonlinear part of DC motor with tail rotor and main rotor,

w_t, w_m Rotational speed of tail rotor and main rotor,

l_t , l_m Effective arm of aerodynamic force from tail and main rotor,

J_h, J_v Nonlinear function of moment of inertia with respect to horizontal axis and vertical axis,

J_{tr} , J_{mr} Moment of inertia in DC motor tail and main propeller subsystem,
S_h, S_v Angular momentum in horizontal plane and vertical plane for the beam,
S_f Constant scaling factor,
k_h, k_v Positive constant,
F_h, F_v Moment of friction force in horizontal plane and vertical plane,
m_{mr} Mass of the main DC motor with the main rotor,
m_m Mass of the main part of the beam,
m_{tr} Mass of the tail motor with the tail rotor,
m_t Mass of the tail part of the beam,
m_{cb} Mass of the counter-weight,
m_b Mass of the counter-weight beam,
m_{ms} Mass of the main shield,
m_{ts} Mass of the tail shield,
l_b Length of the counter-weight beam,
l_{cb} Distance between the counter-weight and the joint,
u_{vv} Output of the vertical DC motor g Gravitational acceleration.

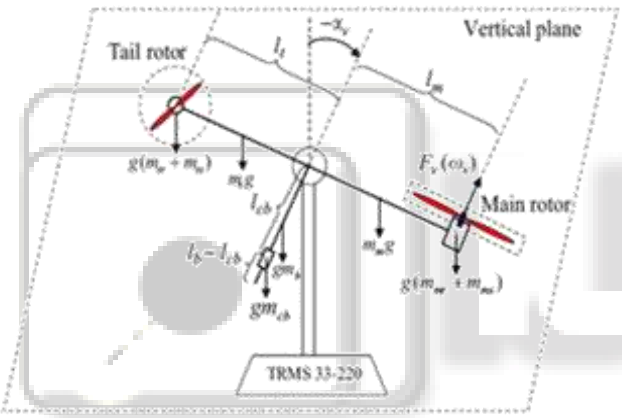


Fig. 2: Gravity and propulsive forces in the vertical plane.

The mathematical model of the tail rotor,

$$\frac{dS_h}{dt} = l_t S_f F_h(w_t) \cos\alpha_v - \Omega_h k_h \quad (7)$$

$$\frac{d\alpha h}{dt} = \Omega_h = \frac{S_h + J_{mr} w_m \cos\alpha_v}{D\sin{\alpha_v}^2 + E\cos{\alpha_v}^2 + F} \quad (8)$$

$$u_{hh} = \frac{U_h}{T_{tr}s + 1} \quad (9)$$

$$\frac{du_{hh}}{dt} = \frac{1}{T_{tr}}(-u_{hh} + U_h) \quad (10)$$

$$w_m = P_h(u_{hh}) \quad (11)$$

Where,

$$F = (m_{ms} r_{ms}^2 + \frac{m_{ts}}{2} r_{ts}^2)$$

r_{ms} Radius of the main shield,
r_{ts} Radius of the tail shield,
u_{hh} Output of the horizontal DC motor.

III. HYBRID PID CONTROLLER USING NEURAL NETWORK

A. *Neural Network Design Steps*

The neural networks are used to solve problems in four application areas: pattern recognition, clustering, function fitting, and time series analysis. The procedure for any of these problems has six primary steps.

(Data collection generally occurs outside the MATLAB environment, so it is step 0.)

1) Collection of data
2) Creation of the neural network.
3) Configuration of the neural network.
4) Initialization of the weights and biases.
5) Training of the neural network.
6) Validation of the network.
7) Use the neural network.

For designing neural network, input and target data is required in certain format.

For controlling Twin rotor mimo system we required a network having three inputs and single output. As the neural network has to be incorporated after PID and has to give output to the system to be controlled, input for neural network taken as the output of P, I, D controllers and For training target, data taken as the output of PID controller.

The capability of neural networks at fitting functions is well known. A fairly simple neural network has ability to fit in any practical function.

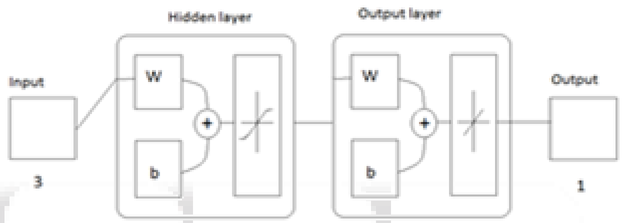


Fig. 4: Proposed structure of neural network

Two-layer feed forward network used. Levenberg-Marquardt back propagation method used to train proposed neural network. The Levenberg-Marquardt algorithm is a variation of Newton's method that was designed for minimizing function that are sums of squares of other nonlinear functions this is very well suited to neural network training where the performance index is the mean square error.

1) The Levenberg-Marquardt algorithm:

$$x_{k+1} = x_k - [J^T J + \mu I]^{-1} J^T e$$

This algorithm has the very useful features that as μ is increased it approaches the steepest descent algorithm with small learning rate.

When the scalar μ is decreased to zero the algorithm becomes Gauss-Newton. When is large, this becomes gradient descent with a small step size.

The algorithm provides a nice compromise between the speed of Newton's method and the guaranteed convergence of steepest descent [7-8].

IV. SIMULATION RESULTS

A. *Twin Rotor MIMO system*

In this section simulation results of highly nonlinear TRMS, considering following expriments -

1) 1 DOF pitch rotor control
2) 1 DOF yaw rotor control
3) 2 DOF control

Fig.5 shows the step response of the twin rotor MIMO system in vertical plane for reference input 0.8 using a hybrid neural network controller. Fig. 6 shows the step response of the twin rotor MIMO system in horizontal plane for reference input 0.5 using a hybrid neural network controller. Fig. 6 (a) and (b) shows the step response of the twin rotor MIMO system in vertical and horizontal for reference input 0.8 & 0.5 respectively using a hybrid neural network controller.

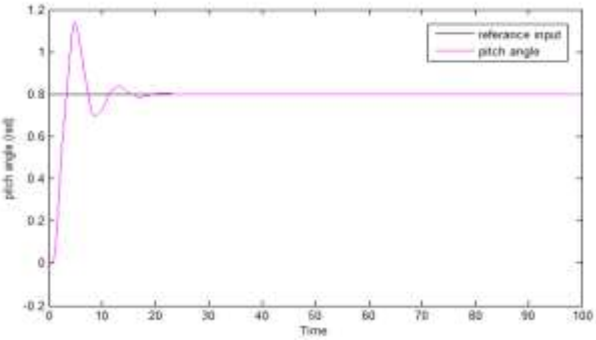


Fig. 5: Step response of the twin rotor MIMO system in vertical plane (Pitch rotor control)

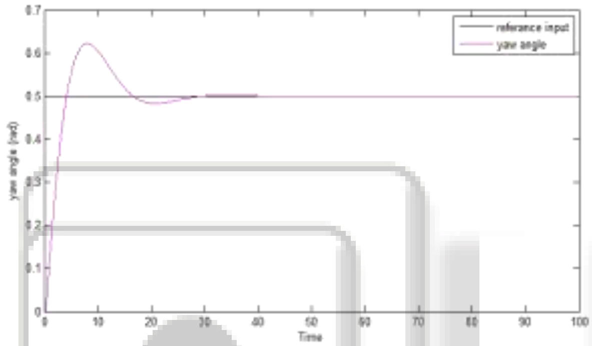
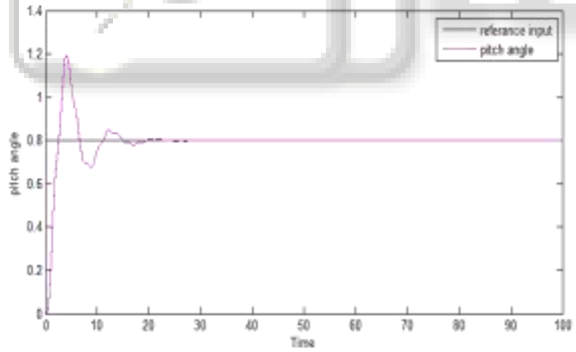
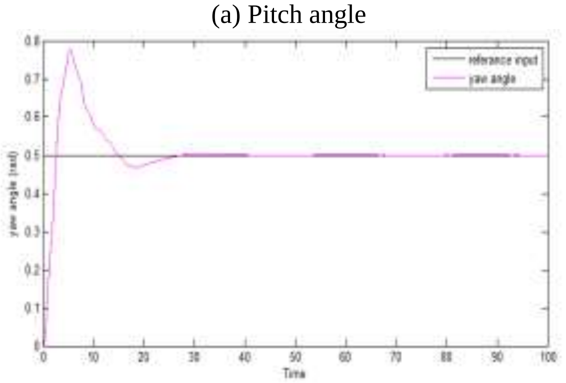


Fig. 6: Step response of the twin rotor MIMO system in horizontal plane (Yaw rotor control)



(a) Pitch angle

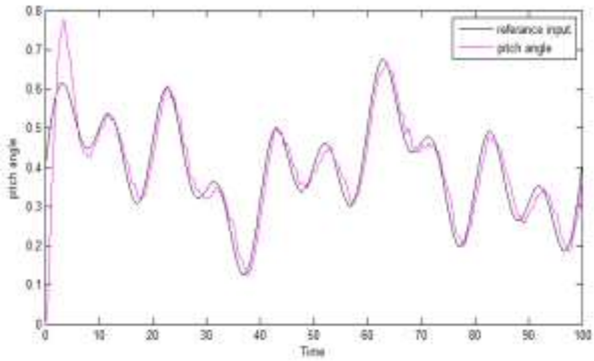


(b) Yaw angle

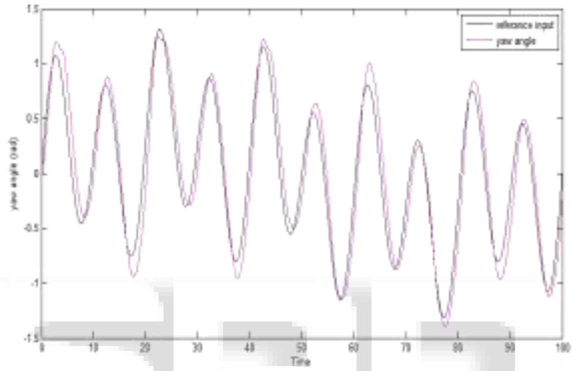
System outputs of TRMS 6(a) and 6(b) are responses of Pitch rotor control and Yaw rotor control from the experiment 2 DOF control

B. *Experimental Validation*

The designed hybrid neural network controller has been tested on real time set up of twin rotor MIMO system (TRMS). The responses, as shown in Fig. 6(a) and 6(b) depict efficacy of the controllers.



(c) Pitch angle



(d) Yaw angle

V. CONCLUSIONS

In this paper, a hybrid neural network technique for controlling TRMS has been developed and implemented.The simulation results show the new approach to control the nonlinear problem for the positioning and tracking performances in real time.

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