INTELLIGENT CONTROL SCHEME FOR NONLINEAR SYSTEMS USING HYBRID NEURAL NETWORK CONTROL TECHNIQUE

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

Keywords—Hybrid; Neural, Twin Rotor Multi Input Multi Output System (TRMS); Nonlinear; Inverted pendulum.

I. INTRODUCTION

Controlling nonlinear systems in real physical systems is a difficult problem due to flexible dynamics, severe nonlinearities, inaccessibility of some states and output for measurement with significant cross coupling. As TRMS and Pendulum are benchmark problem for many important application. Control of Twin Rotor MIMO system is the benchmark problem for control of helicopter and control of pendulum is the benchmark problem for control of application like rocket launching, huge cranes used on shipyard for lifting, Segway etc.

Many intelligent techniques applied to control nonlinear systems like TRMS and Pendulum, among them neural networks [1], fuzzy systems [2] and genetic algorithms [3] are the most popular. In this paper we presented an intelligent hybrid technology in which simple neural network used to tune PID parameter. 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 consists of introduction to Inverted pendulum. Section IV deals with the method of designing the hybrid neural network controller. In section V, the simulation results are presented and last section consists of conclusion.

II 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,

\[ \dot{\omega}_m = \frac{1}{J_m} (\tau_{\text{motor}} - \tau_{\text{aerodynamic}}) \]  

\[ \omega_m = \frac{\tau_{\text{motor}}}{J_m} \]  

\[ \tau_{\text{aerodynamic}} = \frac{2}{5} \rho \pi d^2 \frac{v^2}{2} \]  

\[ w_{\text{aerodynamic}} = \frac{1}{2} \left( \frac{v^2}{2} + g \right) \]  

\[ \tau_{\text{aerodynamic}} = \frac{1}{2} \left( \frac{v^2}{2} + g \right) \]  

Where,

\[ \omega = \frac{1}{2} (\omega_m + w_{\text{aerodynamic}}) \]

...
The inverted pendulum system is formed from a cart, a pendulum and rail for defining the position of the cart. The pendulum is hinged in the center of the top surface of the cart and can rotate around the pivot in the same vertical plane with the rail. The cart can move right or left on the rail freely. It has inherently two states i.e. stable and the unstable. The stable state is undesirable state and the pendulum is downward oriented. In unstable state pendulum orient strictly upward and hence, requires a counter force to stay align to this position because disturbance will shifts the rod away from equilibrium [9]. As a typical unstable nonlinear system, inverted pendulum system is often used as a benchmark for verifying the performance and effectiveness of a new control method because of the simplicities of the structure [10]. Such robotic benchmark frequently used to realize experimental models, validates the efficiency of emerging control techniques and verifies their implementation. [11]

Based on principle of the inverted pendulum stabilization, many robotic control strategies are presented. Recent major accomplishments include control design of under actuated robotic systems, mobile wheeled inverted pendulums and gait pattern generation for bipedal and humanoid robots [12].

This benchmark problem of Inverted Pendulum is also applicable for control of applications like Segway, Rocket Launching, on huge lifting cranes on shipyards etc.

Mathematical modelling of Inverted Pendulum,

\[
\begin{align*}
\dot{a} &= \frac{m_b}{2} \dot{\theta} \dot{\theta}^2 + m_{ms} \dot{\theta} \dot{\psi} + m_{ms} \dot{\Psi}^2 \\
\dot{\Psi} &= \frac{m_b}{2} \dot{\theta} \dot{\theta}^2 + m_{ms} \dot{\theta} \dot{\psi} + m_{ms} \dot{\Psi}^2 \\
\end{align*}
\]

Where,

- \( m_b \) is the mass of the main shield,
- \( m_t \) is the mass of the tail shield,
- \( \omega_{ms} \) is the output of the horizontal DC motor.

III. INVERTED PENDULUM

Motion of inverted pendulum has both translational and rotational movement. Let \( H \) the horizontal component of reaction force and \( V \) be vertical component of reaction force. Let \( x_1 \) be the horizontal component of reaction force and \( y_1 \) be the vertical component of reaction force.
component of co-ordinates of Centre of Gravity (COG) and \( y_1 \) be the vertical component of co-
ordinates of COG.
\[
\begin{align*}
x_1 &= x + l \sin \theta \\
y_1 &= l \cos \theta \\
x_1 &= x + l \theta \cos \theta \\
y_1 &= l \theta \sin \theta
\end{align*}
\]
Define the angle of the rod from the vertical (reference) line as \( \theta \) and displacement of the cart as \( x \). Also assume the force applied to the system is \( F \), \( g \) be the acceleration due to gravity and \( l \) be the half length of the pendulum rod, \( v \), and \( w \) be the translational and angular velocity of the cart and pendulum.
Let \( H \) the horizontal component of reaction force and \( V \) be vertical component of reaction force. So the horizontal reaction force \( H \) becomes:
\[
H = m X_1
\]
The forced \( F \) applied on the cart equals the sum of the force due to acceleration, friction component of force that opposes the linear motion of the cart and the horizontal reaction.
\[
F = M X + b X + H
\]
Thus we get,
\[
F = (m + M) X + b X + mL \theta \cos \theta - mL \dot{\theta}^2 \sin \theta \quad \ldots \quad (12)
\]
The Vertical reaction \( V \) can be expressed as,
\[
V = m Y_1 = -m \dot{\theta} L \sin \theta - m \dot{\theta}^2 L \cos \theta
\]
Torque Equation is given by,
\[
-H \cos \theta \cdot L + (V + mg) \sin \theta = l \dot{\theta} + b \dot{\theta}
\]
Thus,
\[
(1 + mL^2) \dot{\theta} = -mLX \cos \theta - b \dot{\theta} + mgL \sin \theta \quad \ldots \quad (13)
\]
There are two equilibrium conditions for Inverted Pendulum at \( \theta = 0 \) (vertically up) and \( \theta = \pi \) (downwards)

**IV. HYBRID NEURAL NETWORK CONTROLLER**

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.)

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

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.

The Levenberg-Marquardt algorithm:
\[
x_{k+1} = x_k - (J^T \cdot J + \mu I)^{-1} \cdot J^T \cdot g
\]
This algorithm has the very useful features that as \( \mu \) is increased it approaches the steepest descent algorithm with small learning rate.

When the scalar \( \mu \) 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].

**V. SIMULATION RESULTS**

5.1 Twin Rotor MIMO system
In this section simulation results of highly nonlinear TRMS, considering following experiments -

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.

5.2 Inverted Pendulum

There are two equilibrium conditions for Inverted Pendulum at \(\theta=0\) (vertically up) and \(\theta=\pi\) (downwards).

Fig.7 shows result of inverted pendulum stabilization at \(\theta=0\) (vertically up) experiment is shown.

A. 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.

CONCLUSIONS

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

REFERENCES


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