ARTIFICIAL NEURAL NETWORK SLIDING MODE CONTROL FOR MULTI-MACHINE WEB WINDING SYSTEM

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In this work we have presented a study of multi input multi output control structures of multi-motor system using artificial neural network sliding mode control (ANN-SMC). The model of a multi-motor consists of three induction machine which are mechanically coupled. The combination of neural networks with sliding mode control (SMC) methodology is used to eliminate chattering phenomenon and to improve the error performance of SMC. In the approach, two parallel neural networks (NNs) are utilized to realize an ANN-SMC. As demonstrated from simulations, it appears that a comparatively good performance can be reached by the proposed artificial neural network sliding mode controller.

1. INTRODUCTION

The multi-motors systems are considered nonlinear systems and are characterized by structural uncertainties and/or non-structural varying in time, which makes their orders very difficult and complex to implement. For solve this problem, several approaches have been developed. The control scheme based on multi input multi output fuzzy sliding mode control (MIMOSMC) for linear speed regulation of multi-motors system is proposed in [1]. Once the decoupled model of the multi-motors system is obtained, a smooth control function with a threshold was chosen to indicate how far the state from to the sliding surface is [1]. A speed synchronization control strategy for multiple induction motors, based on adjacent cross-coupling control structure, is developed in [2] by employing total sliding mode control method. The proposed control strategy is to stabilize speed tracking of each induction motor while synchronizing its speed with the speed of the other motors so as to make speed synchronization error amongst induction motors converge to zero [2]. The main contribution in [3] consists of designing MIMO sliding mode control law of a distributed parameter based on the original model for which the control variables are coupled [3]. Advanced models for the control of rotary printing presses and related plants are presented in [4]. The model representing micro slip of the moving web between rollers with Coulomb friction is extended to macro slip. The mathematical description of color register errors is extended to doubling errors. New types of cutting register errors are defined taking into consideration printing and non-printing nips [4]. Different strategies for web tension control and linear transport velocity control are presented in [5]. First, an H/sub /spl infin// robust control strategy which reduces the coupling between tension and velocity, is compared to the decentralized control strategy with proportional integral derivative (PID) controllers commonly used in the industry. Second, an H/sub /spl infin// robust control strategy with varying gains is shown to render the control more robust to the radius variations. Then, a linear parameter varying (LPV) control strategy with smooth scheduling of controllers is synthesized for different operating points and compared to the previous methods. Finally, this LPV control and the H/spl infin// robust control strategy with varying gains are combined to give the best results on an experimental setup, for the rejection of the disturbances introduced by velocity variations and for the robustness to radius and inertia changes [5]. The decoupled adaptive fuzzy sliding mode control (SMC) for robotic manipulators is presented in [6]. This controller is proposed for a class of multiple-input multiple-output (MIMO) systems with unknown non-linear dynamics. Indeed, an online fuzzy adaptation scheme is suggested to approximate unknown non-linear functions to design SMC [6]. A stable adaptive fuzzy sliding-mode controller is developed in [7] for nonlinear multivariable systems with unavailable states. When the system states are not available, the estimated states from a semi-high gain observer are used to construct the output feedback fuzzy controller by incorporating the dynamic sliding mode. It is proved that uniformly asymptotic output feedback stabilization can be achieved with the tracking error approaching to zero [7]. In this work the hybrid of ANN and SMC to control a winding system are proposed in order to improve the performances of the control system, which are coupled mechanically, and for the rejection of the disturbances introduced by velocity variations and for the robustness to radius and inertia changes. Finally, this LPV control and the H/spl infin// robust control strategy with varying gains are combined to give the best results on an experimental setup, for the rejection of the disturbances introduced by velocity variations and for the robustness to radius and inertia changes [5].

2. SYSTEM MODEL

Figure 1 shows the multi-motors systems which consist three phase induction motors type which each one is supplied by an inverter voltage, the motor M1 for unwinding, M2

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drives the fabric by friction and M3 is used to winding. The objective of these systems is to maintain the tape speed constant and to control the tension in the band [1–3].

![Image of three motors web transport system](image)

The dynamic model of three-phase, Y-connected induction motor can be expressed in the d-q synchronously rotating frame as [1, 2]:

\[
\frac{d}{dt}\begin{bmatrix}
L_s \frac{d}{dt} i_d \\
L_s \frac{d}{dt} i_q
\end{bmatrix} = \begin{bmatrix}
r_s + \left( \frac{L_m}{L_r} \right)^2 & \sigma L_s \omega_s i_q \\
\sigma L_s \omega_s i_d & 0
\end{bmatrix} \begin{bmatrix}
i_d \\
i_q
\end{bmatrix} + \begin{bmatrix}
\frac{L_m}{L_r} \cdot R_r & \sigma L_s \omega_s \\
\frac{L_m}{L_r} & 0
\end{bmatrix}\begin{bmatrix}
i_d \\
i_q
\end{bmatrix},
\]

(1)

\[
\frac{d}{dt}\begin{bmatrix}
\frac{d}{dt} q_d \\
\frac{d}{dt} q_r
\end{bmatrix} = \begin{bmatrix}
L_m \cdot \varphi_d & L_m \cdot \varphi_r \\
R_r \cdot \omega_r & \varphi_d + \left( \frac{L_m}{L_r} \right) \cdot \omega_r
\end{bmatrix} \begin{bmatrix}
q_d \\
q_r
\end{bmatrix} - \begin{bmatrix}
L_m \cdot \varphi_d \\
R_r \cdot \omega_r
\end{bmatrix} \begin{bmatrix}
q_d \\
q_r
\end{bmatrix} + \begin{bmatrix}
L_m \cdot R_r & \sigma L_s \omega_s \varphi_r \\
\sigma L_s \omega_s \varphi_d + \left( \frac{L_m}{L_r} \right) \cdot \omega_r
\end{bmatrix} \begin{bmatrix}
\frac{d}{dt} \omega_d \\
\frac{d}{dt} \omega_r
\end{bmatrix} + \begin{bmatrix}
L_m \cdot \varphi_d - \omega_r \varphi_r \\
R_r \cdot \omega_r
\end{bmatrix},
\]

(2)

\[
\frac{d}{dt}\begin{bmatrix}
\frac{d}{dt} \omega_d \\
\frac{d}{dt} \omega_r
\end{bmatrix} = \begin{bmatrix}
P^2 L_m & \sigma L_s \omega_s J \varphi_d - \varphi_d \\
\sigma L_s \omega_s J \varphi_d - \varphi_d & 0
\end{bmatrix} \begin{bmatrix}
\omega_d \\
\omega_r
\end{bmatrix} - \begin{bmatrix}
P \frac{J}{J} \omega_r \\
\frac{J}{J} \omega_r
\end{bmatrix} T
\]

(3)

where \(E\) is the Young modulus, \(S\) is the web section and \(f_k\) is the roller viscous friction coefficient, \(R_k\) is the radius of roll \(k\), \(L\) is the web length; \(V_i\) is the linear velocity of the web on roll \(k\) \((i = 2, 3\) and \(k = 1, \ldots, 3\).

The \(k\)-th electromagnetic torques can be expressed as follow:

\[
C_{emk} = \left( i_{qs,k} \varphi_{dr} - i_{ds,k} \varphi_{qr} \right),
\]

(4)

3. MIMO ANN

SLIDING MODE CONTROL (ANN-SMC)

Consider the class of nonlinear time varying systems described by the equations:

\[
\dot{X} = f_j (X_1, \ldots, X_m) + b_j (X_1, \ldots, X_m) u_j ,
\]

(10)

where \(u_j\) is the \(j\)-th control input, and \(X = [X_1, \ldots, X_m]^T\).

In (10) the function \(f_j\), the control gain \(b_j\), and the disturbance \(d_j\) are assumed to be unknown. The dynamics of (10) describe a large number of nonlinear systems encountered in practice, including a vast class of controllable nonlinear systems that could be converted into (10) by using appropriate transformations [6–9].

Under matrix form, the mechanical model can write itself under the following form:

\[
\dot{X} = F(t, x) + B(t, x)^* U ,
\]

(11)

where \(U = [C_{em1}, C_{em2}, C_{em3}]^T\).

The sliding surface is

\[
S_i = V_i^* - V_i , \quad i = 1, 2, 3.
\]

(12)

The derivative surface is

\[
\dot{S}_i = V_i^* - V_i = = \left( \frac{1}{R_i(t)} \frac{dR_i(t)}{dt} - \frac{1}{J_i(t)} \frac{dJ_i(t)}{dt} - \frac{f_j(t)}{J_i(t)} \right) V_i + \frac{R_i^2(t)}{J_i(t)} (T_2 - T_1) + \frac{R_i(t)}{J_i(t)} C_{em1},
\]

(13a)

\[
\dot{S}_2 = V_2 - V_2 = = \left( \frac{1}{R_2(t)} \frac{dR_2(t)}{dt} - \frac{1}{J_2(t)} \frac{dJ_2(t)}{dt} - \frac{f_j(t)}{J_2(t)} \right) V_2 + \frac{R_2^2(t)}{J_2(t)} (T_3 - T_2) + \frac{R_2(t)}{J_2(t)} C_{em2},
\]

(13b)
Artificial neural network sliding mode control for multi-machine

\[
\begin{aligned}
S_3 &= V_3 - \dot{V}_3 = \\
&= \left( \frac{1}{R_3(t)} \frac{dR_3(t)}{dt} - \frac{1}{J_3(t)} \frac{dJ_3(t)}{dt} - \frac{f_J(t)}{J_3(t)} \right) V_3 + \\
&\quad + \frac{R_3^2(t)}{J_3(t)} ( -T_3 ) + \frac{R_3(t)}{J_3(t)} C_{em3}.
\end{aligned}
\] (13c)

It can be written as follows

\[
\dot{S}(x) = F(t,x) + D(t,x)U,
\]
where \( x = [V_1 \quad V_2 \quad V_3] \).

Fig. 2 – Block diagram for multi motors web winding system with ANN-MIMO control.

During the convergence mode, you must check the condition \( S(w_m) \cdot \dot{S}(w_m) < 0 \).

Figure 2 shows the ANN-SMC control strategy scheme for multi motors web winding system.

By substituting the expression of the equivalent control \( U_{eq} \) in the expression for the derivative of the surface, we obtain:

\[
\dot{S}(x) = F(t,x) + D(t,x) (U_{eq} + U_n)
\]

Therefore

\[
U_n(x,t) = K_{NN} \chi_n (S^n \left/ \zeta_n \right.),
\]

where

\[
\chi_n (S^n) = [\text{sat}(S^n_1(x)) \text{sat}(S^n_2(x)) \text{sat}(S^n_3(x))],
\]

\[
K_j = \begin{bmatrix} K_1 & 0 & 0 \\ 0 & K_2 & 0 \\ 0 & 0 & K_3 \end{bmatrix}
\]

The condition therefore satisfies \( K_i > 0 \) therefore satisfies the condition of attractiveness to the intersection of switching surfaces.

The equivalent control of the equation (18) can be written as follows

\[
U_{eq}(x,t) = K_i \chi_n (S^n \left/ \zeta_n \right.),
\]

where \( K_i = K_{NN} K_i \) and \( \zeta_n = \alpha_{NN} \zeta_n \).

In this approach we have replaced the adaptation that adjusts the parameter of the equivalent control (\( K_i \) and \( \zeta_n \)). We have chosen an ANN structure with two inputs (\( dS \) and \( S \)) and one output \( \alpha_{NN} \). The ANN consists of three layers, the input layer has two neurons with no activation function, the hidden layer has (10) neuron with log-sigmoid function, and the output layer has one neuron with log-sigmoid function, the structure of ANN is shown in Fig. 3. The ANN is trained using the data of SMC control.
4. SIMULATION RESULTS

We use MATLAB/SIMULINK software to simulate and evaluate the multi motors systems under the following conditions: start with the linear speed of the three motors 20 m/s, the motor M1 for unwinder with radius $R_1$ ($R_1 = 2.25$ m) and the motor M3 has the role of winding a roll of radius $R_3$.

Figures 4–6 show that the effect of the disturbance is neglected in the case of the ANN-SMC controller. It appears clearly that the classical control with PI and SMC controller is easy to apply. However, the control with ANN-SMC offers better performance in the overshoot control.

Comparing the results obtained with PI controller and SMC controller is shown in Figs. 4–6. According with this comparison we can judge that the ANN-SMC controller has a net improvement in performance control compared to PI-controller, synchronism between the three motors is improved, the linear speed has follows the reference speed in all controller, but the overshoot in linear speed of unwinder is 25 % is shown in PI controller.

Figures 4–6 show that with the ANN-SMC control, the system follows the reference speed after 0.5 s in all motors, however, in the PI controller the system follows after 1 s.
The sliding mode control of the multi motor system show the effectiveness and performances of the developed control scheme but the problem of this type of control is the sudden variation (chattering phenomenon.). To reduce the effects of this phenomenon and to further improve the control performance of multi-motor system, a hybrid of Artificial Neural Network and sliding mode was developed. This control technique is Artificial Neural Network system that generates the parameters of the equivalent component of the control law by sliding multi-variable mode (ANN-SMC). Simulation results show the robustness of the developed control (ANN-SMC), which gave better results compared to the PI-MIMO and SMC-MIMO.

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