MRAC BASED DC SERVO MOTOR MOTION CONTROL

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ABSTRACT

Adaptive Control strategies helps to get desirable output for system with partial unknown dynamics or systems having unknown and unmodeled load variation. DC servo motors are useful to track rapid speed trajectory for various applications, particularly with need of high starting torque and low inertia. Model Reference Adaptive Control (MRAC) parameter data of results with Lyapunov stability MRAC has been used to generate adaptation parameter for DC motor speed controller. Based on the data of error and adaptation parameter new ANFIS based controller has been created and trained. ANFIS based MRAC controller determines parameter based on present value of error for each iteration. Problem definition, adaptive controller using model output as a reference, basic block diagram of overall system and derivation of control law has been presented. Introduction part discusses literature survey, development of the topic and importance of the work.

Key words: ANFIS, Lyapunov Stability, MRAC Motion Control, Servo

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1. INTRODUCTION

Control system should be able to help achieving desirable response for a given set of specifications. More important aspect is stability of system with accuracy as per need of the application. High starting torque and low inertia motors are essentials for motion control applications. DC servo motors are useful for rapid changes in velocity
for various applications. Model of DC servo motor and related control strategies for speed control have been discussed here. MRAC technique based on Lyapunov stability has been used to generate adaptation parameter for controller. Based on the data set of model output, plant output and adaptation parameter new ANFIS based controller has been created and trained. ANFIS based MRAC controller has been to control speed of the servo motor. Problem identification and definition, Lyapunov stability based and ANFIS based adaptive controller using model output as a reference, basic block diagram of overall system with controller and adaptive mechanism, application and derivation of control law has been presented. This section of the paper discusses literature survey, development of the topic and importance of the work.

Fundamentals of adaptive control, Development of adaptive control techniques and advanced trends with applications have been rigorously compiled and nicely discussed in [1]. This book contributes in depth analysis for adaptive control, stability considerations and emphasizes MRAC as an important control strategy. Present challenges, strength and features of adaptive control, have been reviewed and common and uncommon issues about applying MRAC to process with time delay are discussed in [2].

Researchers have suggested various strategies to apply soft computing based controller. The model of generalized servo systems has been discussed in [3]. A linear and adaptive DC type servo drive control system on basis of an observer theory and on the basis of a theory of passive adaptive control is proposed in [4] for better drive performance for DC servo motor. In [5] the speed control method with robustness for a DC servo motor has been proposed to deal with problems like variation in values of parameter and disturbance torque. Direct method of Lyapunov helps restrain effect of estimation error. With a quantitative as well as qualitative study of fuzzy controller [6] presents method for motion control using FLC for a separately excited D.C motor and emphasizes that the controllers with fuzzy logic are applied widely with simple configurations and their analytical knowledge has greater scope of improvement.

A robust observer to estimate state and to estimate fault having decoupling of unknown input has been designed and robust natured fault tolerant control for discrete-time linear process has been proposed in [7]. Design and analysis of an intelligent control to achieve position tracking with high-precision for manipulator of n-link robot is addressed in [8]. A robust natured neural fuzzy system based network control is proposed to the position control for joint of an n link robot system manipulator actuated by dc servo motors for periodic motion and Lyapunov stability has been discussed for said approach. Equivalency of quantized system is proved to the original one, on the sliding manifold in case of ideal value of sliding, for bit stream based strategy of feedback control in [9].
Figure 1 Block Diagram of Servo Motor Motion MRAC

MRAC based on Dynamic Back Propagation and Fuzzy Emulator for Converter application has been discussed in [10]. Output of master system has been used to choose model for reference and T-S fuzzy model has been used to present the chaotic and discrete-time slave nature system in [11]. With the fuzzy state estimator, and by combination of the adaptive control backstepping technique with the decentralized system design in[12] an adaptive decentralized output feedback control fuzzy approach has been developed. For suggested control approach semi-globally and uniformly and ultimately bounded probable value has been assured.

In [13] the sum of the output of conventional MRAC provide I/O of the neural / fuzzy controller. Supervisory loop with intelligence has been incorporated with the conventional MRAC framework design by using an online neural and fuzzy network structure in parallel with it. Modeling with control orientation, design, structures and simulation work with various techniques and control law strategies, result analysis details and advanced control algorithms have been discussed in book [14]. A gradient scheme known as the MIT rule is given by

$$\frac{d\theta}{dt} = -\gamma e \frac{d}{\theta}$$

where, error $e = y - y_m$, $\gamma$ is adaptation gain and $\theta$ is for adjustment mechanism. Fig. 1 shows basic block diagram for proposed system. After MIT rule based MRAC [15] various modifications were suggested by researchers. A summary and rigorous compilation of all methods, control techniques and study of application has been carried out in [16].

ANFIS based Robot manipulator control has been proposed in [17].NN control and ANFIS based results have been compared with and without disturbance. Importance of soft computing technique based MRAC with past and recent publication survey has been discussed in [18]. MRAC sections classified in survey paper are based on applications, techniques and soft computing. Optimal criterion for energy efficiency should be given higher importance in design [19]. Mechatronic devices normally performs well but are intrinsically energy intensive. It affects overall system sustainability so energy optimal motion is needed.

Adaptive and fuzzy based output tracking using backstepping control technique has been performed in [20] and unknown nonlinear part has been identified using a fuzzy logic system. Optimal observer design using soft computing has been applied for HJB equation based algorithm in [21]. A neural adaptive controller for DC motor tracking problem is discussed in [22]. Existing techniques have been integrated in [23], such as the linearization technique for I/O, application of NN to linearize equation of control law, the network estimation errors are compensated with the
Effective sliding mode control scheme and Lyapunov approach has been used to update the neural network parameters. The DC servo motor with fixed and variable load has been used in [24] for the plant response and the Self-tuning adaptive controller with parameter estimation. Application of a direct Fractional order MRAC to an Automatic Voltage Regulator has been discussed in [25]. Soft computing tool genetic algorithm has been used for optimization. STCs are mostly with base of the certainty equivalence and is only suboptimal. Adaptive dual control, the bicriterial approach has been suggested to improve the quality [26].

Error addressed in this work is type 2 model presented in error models part of [27]. The book contributes about adaptive systems from fundamentals to applications. The architecture and procedure of learning with ANFIS have been presented in [28]. Information about each layer of ANFIS, training, evaluation and related regression part is covered in [29, 30]. Use of such strategy to generate adaptation parameter and prove system stability for the adapted controller parameter has been discussed here. NN based MRAC has been compared with classical MRAC in [31]. With focus on multivariable processes and systems, identification, control, design, analysis and implementation of nonlinear and linear systems have been covered in [32]. Robust, nonlinear and adaptive control has nicely been introduced and covered and many generalized solutions for control have been derived with proof in [33]. The work is useful to derive Lyapunov based MRAC as a base for ANFIS based MRAC.

In this paper now section II presents use of ANFIS for parameter adaptation. Section III discusses motion control study for DC servo motor. It also presents generalization of Lyapunov based MRAC, simulation work and results and discussion. Sections IV gives conclusion for the work done.

2. ANFIS STRUCTURE FOR PARAMETER ADAPTATION

Adaptive neuro fuzzy type inference system is used to replace Lyapunov stability based adaptive controller. Data set of plant output, model output and generated adaptation parameter $\theta$ for the control using Lyapunov stability based MRAC has been used to train data. The generalized bell function with assumed three parameters $\alpha, \beta,$ and $\gamma$ for error input is given by

$$\mu = \mu(e, \alpha, \beta, \gamma) = \frac{1}{1 + \left| \frac{e - \gamma^2}{\alpha} \right|^\beta}$$

(01)

In layer 2 nodes are fixed with its output as the product of all their entry inputs. As normalization is important, in next layer normalization takes place. After calculation of consequent evaluation interference in layer 4, the overall output after layer 5 is

$$\hat{\theta} = \frac{\sum w_i f_i}{\sum w_i}$$

(02)
3. DC SERVOMOTOR MOTION CONTROL

Servo systems drive and control position and time derivatives of position. Armature closed loop control is applied if size of servo motor is large and high torque is required.

3.1. About System and Model

The considered system can be expressed as follows.

\[ L_a \frac{di_a}{dt} + R_a i_a + k_b \omega = e_a \]  

(03)

\[ j \frac{d\omega}{dt} + f \omega = k_i i_a \]  

(04)

Fig. 3 shows working of DC servomotor. Based on resistance, inductance and back emf system produces resultant speed for a provided value of armature voltage. Two proportionality constants for back emf and torque have been used.

Control problem is to follow desirable reference trajectory speed. Control input here is armature voltage input to the system. Even though original system parameter changes, the system output should follow the model output.
### 3.2. Parameter Adaptation and Control Law

Model output represented as
\[ \dot{y}_m = -A_m y_m + B_m u_m \]  
(05)

and plant
\[ \dot{y} = -A_m y + bu \quad \text{where} \quad u = \partial u_m \]  
(06)

So
\[ \dot{e} = -A_m e + (b\theta - B_m)u_m \]  
(07)

To update adaptation parameter we consider both e and \( \dot{e} \)

Let \( e'_j = \gamma e \)

Let a Lyapunov function
\[ V(e'_j, \theta) = \frac{1}{2}(e'_j)^2 + \frac{1}{2b\gamma}(b\theta - B_m)^2 \]  
(08)

Derivative term of Lyapunov function
\[ \dot{V} = e'_j e'_j + \frac{1}{\gamma}(b\theta - B_m)\dot{\theta} \]  
(09)

\[ \dot{V} = \gamma e(-A_m e + (b\theta - B_m)u_m) + \frac{1}{\gamma}2(b\theta - B_m)\dot{\theta} \]  
(10)

\[ \dot{V} = -\gamma A_m e^2 + \frac{1}{\gamma}(b\theta - B_m)(\dot{\theta} + \gamma u_m e) \]  
(11)

Taking \( \dot{\theta} = -\gamma u_m e \) gives negative semi definite value for the remaining derivative part of Lyapunov function. So adaptation parameter has been chosen accordingly for stable system.

In DC servomotor motion control, derived \( \dot{\theta} \) can be written as
\[ \dot{\theta} = -\gamma e(\omega_p - \omega_m) \]  
(12)

Similarly, proof can be extended for higher order systems.

Consider following system dynamics to generalize the derivation
\[ \dot{x} = Ax + B\Xi(u - f(x)) \]  
(13)

where \( x \in \mathbb{R}^n \), \( u \in \mathbb{R}^m \), \( A \in \mathbb{R}^{n \times n} \) system matrix and \( \Xi \) is \( \text{diag}(\xi_1, \xi_2, ..., \xi_m) \in \mathbb{R}^{m \times n} \) unknown matrices and \( \text{sgn}(\xi_i) \) is known for \( i = 1, 2, ..., m \), \( B \in \mathbb{R}^{m \times n} \) is known and constant matrix, Uncertain function \( f(x) = \Theta^T \Phi(x) \in \mathbb{R}^m \) with matrix of unknown constant parameters \( \Theta \in \mathbb{R}^{m \times n} \), \( n \) basis functions with known value is \( \Phi(x) = (\phi_1(x), \phi_2(x), ..., \phi_{n-1}(x), \phi_n(x))^T \)
Stable Reference Model
\[ \dot{x}_m = A_m x_m + B_m u_m \]  
\[ u_m \in \mathbb{R}^m, \quad A_m \in \mathbb{R}^{m \times m}, \quad B_m \in \mathbb{R}^{m \times n} \]  
The goal is to have zero error, means
\[ \lim_{t \to \infty} \|x(t) - x_m(t)\| = 0 \]
Assume control law with parameter estimation
\[ u = \hat{k}_x^T x + \hat{\Theta}^T \Phi(x) \]  
Thus, \( \hat{k}_x^{\text{mon}} \) and \( \hat{\Theta}^{\text{mon}} \) Parameters need to be estimated for adaptation.
\[ \dot{x} = (A + B\Xi\hat{k}_x^T)x + B\Xi(\hat{\Theta}^T - \Theta)^T \Phi(x) \]  
Model representing desired dynamics is (2). When system dynamics follows model dynamics, terms can be compared as \( A + B\Xi\hat{k}_x^T - A_m = B\Xi(\hat{k}_x - k_x)^T \) and
\[ B\Xi(\hat{\Theta}^T - \Theta)^T - B_m = 0 \]
Tracking error dynamics given by
\[ \dot{e}(t) = ((A + B\Xi \hat{k}_x^T)x + B\Xi((\hat{\Theta}^T - \Theta)^T \Phi(x)) - A_m x_m - B_m u_m - A_n x + A_n x) = (\dot{x}(t) - \dot{x}_m(t)) \]  
\[ \dot{e} = A_m e + B\Xi(\Delta k_x^T x + \Delta \Theta^T \Phi(x)) \]  
The Lyapunov function is
\[ V(e, \Delta k_x, \Delta \Theta) = e^T P e + \text{trace}(\Delta k_x^T \gamma_s^{-1} \Delta k_x \Xi) + \text{trace}(\Delta \Theta^T \gamma_\Theta^{-1} \Delta \Theta \Xi) \]
Where \( P = P^T > 0, \gamma_s = \gamma_s^T > 0 \) and \( \gamma_\Theta = \gamma_\Theta^T > 0 \) are symmetric positive definite matrices.
\[ P \] is the solution of \( PA_m + A_m^T P = -Q \)  
Choosing adaptive laws
\[ \dot{\hat{k}}_x = -\gamma_s xe^T PB \text{sgn}(\Xi) \]
\[ \dot{\hat{\Theta}} = -\gamma_\Theta \Phi(x)e^T PB \text{sgn}(\Xi) \]  
\[ V = -e^T Q e \] becomes negative semidefinite. It indicates Lyapunov stability for the system for applied adaptive MRAC law.

3.3. Simulation work results and discussion
Initially classical Lyapunov based MRAC is applied for the DC servo motor plant and model, with variations in input voltage trajectory. Simulation Parameter values are
Armature resistance \( Ra = 10 \Omega \); Inductance of armature \( La = 300 \) H; \( k_c = 20 \) newton-m/amp; \( j = 8 \) kg-m\(^2\), \( f = 30 \) (newton-m)/(rad/msec), \( k_b = 1.1 \) volts/(rad/msec)
Adaptation gain \( \gamma = 0.7 \) has been used and control law is given by
\[ u = \Theta^* e_p \]
The response seems desirable in both Lyapunov based and ANFIS based MRAC for system, but for partly uncertain plant dynamics, Lyapunov based MRAC is not able to approximate for uncertain part and gives average results. Use of ANFIS to adapt and apply control effort helps for good results in such situations. Fig. 4 presents the value of output and error plot for DC Servo System reference model output. Model output varies based on variation in armature input voltage.

**Figure 4** Output and Error plot for DC Servo System Reference Model Output

Fig. 5 shows adaptation parameter generated with ANFIS and with Lyapunov stability Based MRAC. It shows that approximate model tries to remove oscillations and mostly approximates smooth value for new signal.

**Figure 5** Adaptation Parameter Generated with ANFIS Trained using Data from Lyapunov Based MRAC
Mrac Based DC Servo Motor Motion Control

Figure 6 Lyapunov Function and its Time Derivative for ANFIS Based MRAC

Results shown in Fig. 6 are Lyapunov Function V for MRAC based on adaptation parameter generated by ANFIS and its Time Derivative. Observation shows that positive definite Lyapunov function and negative semidefinite derivative term proves stability of proposed system.

6. CONCLUSION

In this paper MRAC using Lyapunov and ANFIS applied to control motion parameters of DC servo motor. Results are compared for both strategies. It has been observed that ANFIS based MRAC gives better results in terms of error convergence. Introduction, Literature survey, system fundamentals, development of classical MRAC, soft computing and ANFIS based MRAC has been included to understand the importance of the work, problem definition and simulation work. Data of adjustment parameter $\theta$ has been saved after applying Lyapunov based rule and used to apply ANFIS technique to generate $\hat{\theta}$. Lyapunov stability with suitable $V$ and derivation of $\dot{V}$ has been shown. Comparison with other new computing techniques and analysis with case studies of higher order systems may give better vision on future scope, importance and development of the topic.

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REFERENCES

international journal for computation and mathematics in electrical and electronic engineering, Vol. 28, 2009


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[22] Rui Bai “Neural network control-based adaptive design for a class of DC motor systems with the full state constraints”, Neurocomputing Volume 168, 2015


