O IJDACR International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 1, Issue 6, January 2013)

Fuzzy Based Model Adaptive Reference Controller for Nonlinear Systems

Swati Mohore swatimohore@gmail.com

Abstract— The objective of the model reference adaptive fuzzy control. The MRAFC is composed by the fuzzy inverse model and a knowledge base modifier. Because of its improved algorithm, the MRAFC has fast learning features and good tracking characteristics even under severe variations of system parameters. The controller produces the error of the closed loop control system response and the actual system output for the desired system by reference model, instead of ordinary adaptive mechanism. The analysis of dynamic performance for traditional controller and fuzzy adaptive controller is performed in detail with simulation software. Simulation results show that the system is with strong adaptive ability and can adapt to the wide range of changes of the controlled object.

Keywords: Model Reference Adaptive Controller (MRAC), Fuzzy-MRAC Model.

I. INTRODUCTION

The design of nonlinear control systems has been an active research area in recent years. Model free approaches have gained prominence because of the difficulty of finding accurate mathematical models for the systems. Intelligent control techniques that manipulate and implement heuristic knowledge as well as various artificial intelligent algorithms and machine learning techniques are of the most popular approaches. Among these control techniques, there are control algorithms based on artificial neural networks, fuzzy control, and reinforcement learning control.

Under certain assumptions on the plant and reference model, MRAC schemes are designed that guarantee signal boundedness and asymptotic convergence of the tracking error to Zero [4]. These results however provide little information about the rate of convergence and the behavior of the tracking error during the initial stages of adaptation [5-7]. The disadvantage of this MRAC scheme is that it takes some time to adapt and some oscillations will come after a certain period. Hence Dr. Mrs. Shailja Shukla shaija270@gmail.com

modified MRAC is designed. In modified MRAC adaptation time is decreased but this scheme also some oscillation will come after a certain period. The idea behind to design proposed Robust model Reference Adaptive control system is by adding the control signal from the fuzzy controller, to the control signal from modified MRAC.

Professor Whithei presents the Model Reference Adaptive System (MRAS), which is currently a set of matured theory and design method of adaptive control system. MRAS can play a better role for the control of many industry control objects with the environment and parameters of controlled object change. Model reference adaptive control (MRAC) is one of the ways to deal with the uncertainties of plants. Industrial drives are usually subjected to uncertainties in many ways and MRAC such drives are quite capable of dealing with these problems.

However, there are more complex adaptive mechanisms, large amount of design work and hard for computer implementation and other difficulties. Since Ichikawa put forward the innovative design of model reference adaptive fuzzy control, many scholars have made progresses on the application of fuzzy theory to design model reference adaptive system [2].

Generally, the basic objective of adaptive control is to maintain consistent performance of a system in the presence of uncertainty or unknown variation in plant parameters.

Fuzzy control methods have advantages such as robustness, which have been demonstrated through industrial applications [6]. Fuzzy controllers are supposed to work in situations where there is a large uncertainty or unknown variation in plant parameters and structures. In order to deal with the uncertainties of nonlinear systems, in the fuzzy control system literature, a considerable amount of adaptive control schemes have been suggested, [3] [6]-[8]. The main advantages of adaptive fuzzy control is that it give better performance can achieved as fuzzy controller can adjust itself to the changing environment, and less information about



International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 1, Issue 6, January 2013)

the plant is required because the adaptation law can help to learn the dynamics of the plant during realtime operation[8]. expressed as a reference model, which gives the wished response to an input signal. The adjustment mechanism changes the parameters of the regulator by minimizing the error between the system output and the reference model.

II. METHODOLOGY

A. Structure of an MRAC design

The MRAC is one of the major approaches in adaptive control. The desired performance is





III. THE PLANT MODEL AND REFERENCE MODEL SYSTEM

To consider a Single Input and Single Output (SISO), Linear Time Invariant (LTI) plant with strictly proper transfer function

$$G(s) = \frac{y_p(s)}{u_p(s)} = K_p \frac{Z_p(s)}{R_p(s)}$$

Where u_p the plant is input and y_p is the plant output. Also, the reference model is given by

$$G_m(s) = \frac{y_m(s)}{r(s)} = K_m \frac{Z_m(s)}{R_m(s)}$$

Where r and y_m are the model's input and output. Define the output error as

$$e = y_p - y_m$$

Now the objective is to design the control input U_{mr} such that the output error, e goes to zero asymptotically for arbitrary initial condition, where

the reference signal r (t) is piecewise continuous and uniformly bounded. The plant and reference model satisfy the following assumptions:

Assumptions:

1. $Z_p(s)$ Is a monic Hurwitz polynomial of degree $m_{\ensuremath{\mathtt{p}}}$

2. An upper bound n of degree n_p of $R_p(s)$

3. The relative degree $n^* = n_p \cdot m_p$ of G(s)

4. The sign of the high frequency gain K_p are known

 $5.Z_m(s), R_m(s)$ are monic Hurwitz polynomials of degreeq_m, p_mrespectively, where

$$p_m \le n$$

6. The relative degree $n_m^* = q_m$, p_m of Gm(s) is the same as that of G(S), i.e., $n_m^* = n^*$

Relative Degree n =1

Following input and output filters are used,

O IJDACR International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 1, Issue 6, January 2013)

$$\dot{\omega}_1 = F\omega_1 + gu_p$$
$$\dot{\omega}_2 = F\omega_2 + gy_p$$

Where *F* is an $(n-1)^*(n-1)$ stable matrix such that det (SI - F) is a Hurwitz polynomial whose roots include the zeros of the reference model and that (F, g) is a controllable pair. It is defined as the "regressor" vector

$$\omega = \left[\omega_1^T, \omega_2^T, y_p, r\right]^T$$

In the standard adaptive control scheme, the control U_{mr} is structured as

$$U_{mr} = \theta^T \omega$$

Where $\theta = [\theta_1, \theta_2, \theta_3, C_0]^{\text{T}}$ is a vector of adjustable parameters, and is considered as an estimate of a vector of unknown system parameters θ^* . The dynamic of tracking error

$$e = G_m(S)P^*\tilde{\theta}^T\omega$$

Where $P^* = K_p/K_m$ and $\tilde{\theta} = \theta(t) - \theta^*$ represents parameter error. Now in this case, since the transfer function between the parameter errors $\tilde{\theta}$ and the tracking error *e* is strictly positive real (SPR), the adaptation rule for the controller gain θ is given by $\dot{\theta} = -\Gamma e_1 \omega \text{sgn}(p^*)$ Where Γ is a positive gain

Relative Degree n = 2

In the standard adaptive control scheme, the control U_{mr} is structured as

$$U_{mr} = \theta^{T} \omega + \dot{\theta}^{T} \Phi$$

= $\theta^{T} \omega$
- $\theta^{T} \Gamma \Phi e_{1} \operatorname{sgn}(K_{p}/K_{m})$

Where $\theta = [\theta_1, \theta_2, \theta_3, C_0]^T$ is a vector of adjustable parameters, and is considered as an estimate of a vector of unknown system parameters θ^* . The dynamic of tracking error is

$$e = G_m(s)(s + p_0)p^*\tilde{\theta}^T \Phi$$

Where $P^* = \frac{K_p}{K_m}$ and $\tilde{\theta} = \theta(t) - \theta^*$ represent the parameter error. $G_m(s)(s + p_0)$ Is strictly proper and Strictly Positive Real (SPR). Now in this case, since the transfer function between the parameter error $\tilde{\theta}$ and the tracking error *e* is SPR, and the adaptation rule for the controller gain θ is given

$$\dot{\theta} = -\Gamma \Phi e_1 \text{sgn}(\frac{K_p}{K_m})$$

Where $e_1 = y_p \cdot y_m$ and Γ is a positive gain.

The adaptive laws and control schemes developed are based on a plant model that is free from disturbances, noise and unmodelled dynamics. These schemes are to be implemented on actual plants that most likely to deviate from the plant models on which their design is based. An actual plant may be infinite in dimensions, nonlinear and its measured input and output may be corrupted by noise and external disturbances. It is shown by using conventional MRAC that adaptive scheme is designed for a disturbance free plant model and may go unstable in the presence of small disturbances.

IV. FUZZY ADAPTIVE MODEL REFERENCE CONTROL SYSTEM

In the control system, the fuzzy adaptive controllers together with the controlled object constitute the closed-loop system with adjustable parameters. The controller uses the indirect control method, which is firstly modeling the controlled object by the fuzzy logic system, and then producing the desired control action. The fuzzy logic system can get approaching the controlled object by regulating the adjustable parameters, so that the output of the system under certain conditions can track the reference model output for any precision. O IJDACR International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 1, Issue 6, January 2013)



Figure.2 Simulink Model of the proposed Fuzzy-MRAC scheme

O IJDACR

International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 1, Issue 6, January 2013)

Considering nonlinear discrete system

y(t + 1) = g(t) + h(t)u(t)

Where g(t), h(t) are unknown nonlinear functions, and

 $g(t) = g(y(t), y(t-1), \dots, y(t-n1+1), u(t), u(t-1), \dots, u(t-n2+1))$

 $h(t) = h(y(t), y(t - 1), \dots, y(t - m1 + 1), u(t), u(t - 1), \dots, u(t - m2 + 1))$

 $k \ge n_1, n_2, m_1, m_2; u(t) \in R \text{ and } y(t) \in R \text{ are the input and output of the system.}$

Suppose g(t) and h(t) can be measured and estimated by small samples, with $h \neq 0$ and t = (0,1,2,...). The control task is to make the output of controlled system tracking a given bounded reference signal $y_m(t + 1)$ with the constraints that all the signals are bounded. So the control purpose is to derive a feedback control signal u(t) and adaptive law of an adjustable vector W(t) for

1. in all variables W(t) and u(t) uniformly bounded sense, the system output error e(t+1) =

 $y_m(t + 1) - y(t + 1)$ Is as small as possible;

2. Under certain conditions, the adjustable system is with global asymptotic stability.

For the system as depicted in (1), if g(t) and h(t) are known, using the control law

$$U_c(t) = 1/h(t)[-g(t) + y_m(t+1)pe(t)]$$

Where p < 0 is the feedback gain, then the output error of the system is

$$e(t + 1) = ym(t + 1) - y(t + 1)$$

= $ym(t + 1) - [g(t) + h(t)uc(t)]$
= $ym(t + 1) - [g(t) + h(t)1 + \frac{h(t)[-g(t) + y_m(t + 1)pe(t)]}{h(t)[-g(t) + y_m(t + 1)pe(t)]}]$
= $ym(t + 1) - ym(t + 1) - pe(t)$
= $-pe(t)$

Then it can be seen that if |p| < 1, the output of adjustable system can asymptotically track the reference model output ym(t + 1). Since g(t) and h(t) are unknown continuous functions, if they are substituted by fuzzy inference system $\hat{g}(t)$ and $\hat{h}(t)$ respectively, let the control law be

 $U_c(t) = 1/\hat{h} (t) [-\hat{g}(t) + y_m(t+1)pe(t)]$ Then

$$\begin{split} y(t + 1) &= g(t) \\ &+ h(t)1 \\ &/\hat{h} \ [-\hat{g} \ (t) + y_m(t + 1)pe(t)] \end{split}$$
 According to equation (U_c(t)), $U_c(t) &= \frac{1}{h(t)[-g(t) + y_m(t + 1)]} + \frac{1}{\hat{h}} \ (t)pe(t) \\ &= u_c' + \frac{1}{\hat{h}} \ (t)pe(t) \end{split}$

Where $u'_{c} = 1/\hat{h} [-\hat{g}(t) + y_{m}(t+1)]$ $e(t + 1) = -[g(t) - \hat{g}(t)] + \hat{h}(t)u'_{c} - h(t)u'_{c}$ $- p \frac{h(t)}{\hat{h}(t)} r(t)$

Where $\triangle g(t)$ and $\triangle h(t)$ are the identification errors of g(t) and h(t) [2].



Figure: 3.Plant and Reference Model Output-no Control



Figure: 4.Plant and Reference Model Output-PI Control

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 1, Issue 6, January 2013)



Figure: 5.Plant and Reference Model Output-Fuzzy Control



X (input):	е		Ce	Z (output):	Ufc
X grids:	15	Y grids:	15		Evaluate
Ref. Input:		Plot ;	ooints: 101	Help	Close
Ready					

Figure: 6 3D Model for Output-Fuzzy Control

1. If (e is EN) and (ce is EN) then (Ufc is L) (1)

2. If (e is HN) and (ce is EN) then (Ufc is H) (1)

3. If (e is MN) and (ce is EN) then (Ufc is M) (1)

- 4. If (e is SN) and (ce is EN) then (Ufc is M) (1)
- 5. If (e is ZE) and (ce is EN) then (Ufc is M) (1)

6. If (e is MP) and (ce is EN) then (Ufc is H) (1)

7. If (e is HP) and (ce is EN) then (Ufc is L) (1)

8. If (e is EN) and (ce is HN) then (Ufc is H) (1)

9. If (e is HN) and (ce is HN) then (Ufc is M) (1)

10. If (e is MN) and (ce is HN) then (Ufc is M) (1)

11. If (e is SN) and (ce is HN) then (Ufc is NH) (1)

12. If (e is ZE) and (ce is HN) then (Ufc is NH) (1)

13. If (e is MP) and (ce is HN) then (Ufc is H) (1)

14. If (e is HP) and (ce is HN) then (Ufc is L) (1)

15. If (e is EN) and (ce is MN) then (Ufc is M) (1)

16. If (e is HN) and (ce is MN) then (Ufc is M) (1)

17. If (e is MN) and (ce is MN) then (Ufc is NH)(1)

18. If (e is SN) and (ce is MN) then (Ufc is NH) (1)

19. If (e is ZE) and (ce is MN) then (Ufc is NH) (1)

20. If (e is MP) and (ce is MN) then (Ufc is M) (1)

21. If (e is HP) and (ce is MN) then (Ufc is M) (1)

22. If (e is EN) and (ce is SN) then (Ufc is NH) (1)

23. If (e is HN) and (ce is SN) then (Ufc is NH) (1)

24. If (e is MN) and (ce is SN) then (Ufc is NH) (1)

25. If (e is SN) and (ce is SN) then (Ufc is NH) (1)

26. If (e is ZE) and (ce is SN) then (Ufc is NH) (1)

27. If (e is MP) and (ce is SN) then (Ufc is NH) (1)

28. If (e is HP) and (ce is SN) then (Ufc is NH) (1)

29. If (e is EN) and (ce is ZE) then (Ufc is NH) (1)

30. If (e is HN) and (ce is ZE) then (Ufc is NH) (1)



International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary research Website: www.ijdacr.com (Volume 1, Issue 6, January 2013)

31. If (e is MN) and (ce is ZE) then (Ufc is NH) (1)

32. If (e is SN) and (ce is ZE) then (Ufc is NH) (1) $\,$

33. If (e is ZE) and (ce is ZE) then (Ufc is VL) (1)

34. If (e is MP) and (ce is ZE) then (Ufc is NH) (1)

35. If (e is HP) and (ce is ZE) then (Ufc is NH) (1)

36. If (e is EN) and (ce is MP) then (Ufc is L) (1)

37. If (e is HN) and (ce is MP) then (Ufc is H) (1)

38. If (e is MN) and (ce is MP) then (Ufc is M) (1)

39. If (e is SN) and (ce is MP) then (Ufc is NH) (1)

40. If (e is ZE) and (ce is MP) then (Ufc is M) (1)

41. If (e is MP) and (ce is MP) then (Ufc is H) (1)

42. If (e is HP) and (ce is MP) then (Ufc is L) (1)

43. If (e is EN) and (ce is HP) then (Ufc is H) (1)

44. If (e is HN) and (ce is HP) then (Ufc is H) (1)

45. If (e is MN) and (ce is HP) then (Ufc is H) (1)

46. If (e is SN) and (ce is HP) then (Ufc is L) (1)

47. If (e is ZE) and (ce is HP) then (Ufc is EH) (1)

48. If (e is MP) and (ce is HP) then (Ufc is L) (1)

49. If (e is HP) and (ce is HP) then (Ufc is NL) (1)

VI. CONCLUSION

In this paper, a Fuzzy-MRAC scheme is proposed to replace the Neural Network controller. A detailed simulation comparison between the three schemes has been carried out. The proposed Fuzzy-MRAC controller shows very good tracking results when compared to the conventional MRAC and the NN-MRAC system. Simulations and analyses have shown that the transient performance can be substantially improved by proposed Fuzzy-MRAC scheme. Fuzzy-MRAC not only improves performance but also help in reduction of hardware required. Simulation results show that, Fuzzy-MRAC in the severe model mismatch case still can get better control performance, with enhanced satisfied self-adaptability and the resistance ability to internal and external disturbances than the conventional control system significantly.

REFERENCES

[1] Neuro- PI controller based model reference adaptive control for nonlinear systems R. Prakash, R. Anita, International Journal of Engineering, Science and Technology Vol. 3, No. 6, 2011, pp. 44-60

[2] Model Reference Adaptive Controller Design Based on Fuzzy Inference System, Zheng Li, Journal of Information & Computational Science 8: 9 (2011).

[3] S.-W. Kim, Y.-W. Cho, and M. Park, A multirule-base controller using the robust property of a fuzzy controller and its design method, IEEE Trans. On Fuzzy Systems, vol. 4, no. 3, pp. 315-327, Aug., 1996.

[4] Petros.A.Ioannou & Jing Sun, "Robust Adaptive Control", Prentice Hal, second edition, 1996.

[5] Narendra.K.S and A.M. Annaswamy, "Stable Adaptive systems" Prentice-Hall, Second Edition,1989.

[6] M. Maeda and S. Murakami, A self-tuning fuzzy controller, Fuzzy Sets and Systems, vol. 51, pp. 29-40, 1992.

[7] Narendra, K.S, And Valavani, L.: "Stable adaptive controller design – direct control", IEEE Trans. Automat. Contr., AC-23, pp.570-583,1978.

[8] L. -X. Wang, A Course in Fuzzy systems and Control, Prentice-Hall International, Inc., 1997.