

Hover Control for Helicopter Using Neural Network-Based Model Reference Adaptive Controller

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Abstract: *Unmanned aerial vehicles (UAV), have enormous important application in many fields. Quanser three degree of freedom (3-DOF) helicopter is a benchmark laboratory model for testing and validating the validity of various flight control algorithms. The elevation control of a 3-DOF helicopter is a complex task due to system nonlinearity, uncertainty and strong coupling dynamical model. In this paper, an RBF neural network model reference adaptive controller has been used, employing the grate approximation capability of the neural network to match the unknown and nonlinearity in order to build a strong MRAC adaptive control algorithm. The control law and stable neural network updating law are determined using Lyapunov theory.*

Index Terms— Neural Network, Model Reference Adaptive Control, Bench-top Helicopter, Model Uncertainties.

I. INTRODUCTION

UAV control system has greatly improved in the recent years, with the modern technological advance in the computer applications and control theory. There are many difficulties in developing a high performance controller for an unmanned aerial vehicles; due to parametric uncertainty, nonlinearity, under actuation and strong coupling. To overcome these challenges a numerous control algorithm have been suggested to control the attitude of the UAV, in [1] the yaw control of the UAV has studied using the robust H_2 control algorithm. A pitch motion control using neural network-based adaptive feedback proposed in [2]. A sliding mode controller is proposed to improve the tracking performance and error elimination in [3, 4], however sliding mode controller exhibits a chattering phenomenon due to the existence of switching logic in the control law. A hybrid control combining the integral action and the backstepping nonlinear algorithm proposed by W. Gao and Z. Fang in [5] and L. Junfang and et al in [6]. However the main drawbacks for these

methods is that the parameter estimation is growing and depending on the initial conditions of the UAV [7].

In addition a model-based fuzzy control nested saturation control was applied in [8]. A single input interval type-2 fuzzy PID controller and an analytical approach to construct the footprint of the uncertainty of the IT2 fuzzy set is applied in [9]. Neural network offer an advantage over other form of control algorithms, where the nonlinear mapping ability of the neural network is employed for forward and inverse plant modeling. In this paper, a neural network-based model reference adaptive controller has been applied to control the elevation angle of a 3-DOF helicopter. The error between the plant output and the reference model is used to adjust the controller parameters. To compensate the plant nonlinearity the RBF neural network is exploited in the control law. The learning law is obtained using Lyapunov theory. Moreover the whole system stability has been proved.

$$\tilde{\Theta}(t) = \Theta(t) - \Theta^* \quad (10)$$

where $\tilde{\Theta}(t)$ is the weights deviation or weights estimation error vector. As the error between the unknown function $f(x)$ and the RBF neural network output $\hat{f}(x, \Theta(t))$ is not accessible, an alternative approach using the error between the plant output and the reference model is used to generate the learning law for the proposed controller. To prove the stability and derive the NN weights updating law, Lyapunov theory based on the background material in [12, 15] is employed as follow:

Assume that the RBF neural network output is given in matrix form as below:

$$\hat{f}(x, \Theta(t)) = \Theta^T(t) \Phi(x, t) \quad (11)$$

where $\Phi(x, t) \in R^N$ is the radial basis functions output vector. Assume that Ψ and K are diagonal positive definite matrices, and the defined Lyapunov function has the following form:

$$V(e, \tilde{\Theta}(t)) = \frac{1}{2} b_m e^2(t) + \frac{1}{2} \dot{e}^2(t) + \frac{1}{2} \tilde{\Theta}^T(t) \Psi^{-1} \tilde{\Theta}(t) \quad (12)$$

Then the time derivative of $V(e, \tilde{\Theta}(t))$ is

$$\begin{aligned} \dot{V}(e, \tilde{\Theta}(t)) &= b_m e \dot{e} + e \dot{e} + \tilde{\Theta}^T \Psi^{-1} \dot{\tilde{\Theta}}(t) \\ &= -a_m \dot{e}^2 + \tilde{f}(x, \Theta) \dot{e} + \tilde{\Theta}^T \Psi^{-1} \dot{\tilde{\Theta}}(t) \end{aligned} \quad (13)$$

Assume that the learning law is given by:

$$\dot{\Theta}(t) = -\Psi \Phi(x, t) \dot{e}(t) - K \Theta(t) \quad (14)$$

Then (13) can be written in the following form:

$$\begin{aligned} \dot{V}(e, \tilde{\Theta}(t)) &= - \left[a_m - \frac{1}{2\eta^2} \right] \dot{e}^2 \\ &\quad - \left[\mu_1 - \frac{\mu_2}{2\zeta^2} \right] \|\tilde{\Theta}(t)\|^2 \\ &\quad + \frac{1}{2} (\eta^2 |\tilde{f}(x, \Theta^*)|^2 + \mu_2 \zeta^2 \|\Theta^*\|^2) \end{aligned} \quad (15)$$

where

$$\begin{aligned} \mu_1 &= \min_i \{K_i / \Psi_i\} \\ \mu_2 &= |\Psi^{-1} K| \\ \eta \text{ and } \zeta &\in R \end{aligned}$$

It is usually possible to select $\eta^2 > 1/2a_m$ and $\zeta^2 > \mu_2/2\mu_1$; this implies that (8) has strong practical stability.

IV. SIMULATION RESULTS

This section presents the results of a numerical simulation of the proposed neural network based model reference adaptive controller performed to evaluate the hover controlling of a bench-top helicopter and verify the stability of the system and the learning law.

The helicopter system parameters has the following values listed in Table. 1

Parameter	Value	Unit
M	1.426	[Kg]
M_w	1.870	[Kg]
J_ε	1.200	[Nms ²]
l_1	0.200	[m]
l_2	0.060	[m]
l_3	0.185	[m]
d	0.070	[m]
h	0.020	[m]
g	9.810	[m/s ²]

Table.1 Helicopter System Parameters

The reference model is designed such as $a_m = 9$, $b_m = 16$ and $k_m = 1$.

The RBF neural network has 12 neurons for each input with the following parameters:

Initial output weights vector $\hat{\Theta}(0)$ are set to 0.5 and standard deviation vector σ are set to 2. Gaussian membership function mean values which are evenly distributed, are given below for the two inputs:

$$C = [i, i]^T \text{ where } i = -2.5, -2, -1.5, -1, 0.5, -0.25, 0.25, 0.5, 1, 1.5, 2, 2.5.$$

$$\Psi = 19.2 I \text{ and } K = 0.05 I \text{ where } I \text{ is an identity diagonal matrix with proper dimensions.}$$

All the initial values of the system and the reference model are set to zero. Fig. 5 (a) - (c) shows the simulation results for elevation angle tracking as a square wave input. The solid line represent the actual output; the dashed line represent the reference model output. Fig. 6 (a) - (c) shows the simulation results for elevation tracking as sine wave input. The solid line represent the actual output; the dashed line represent the reference model output.

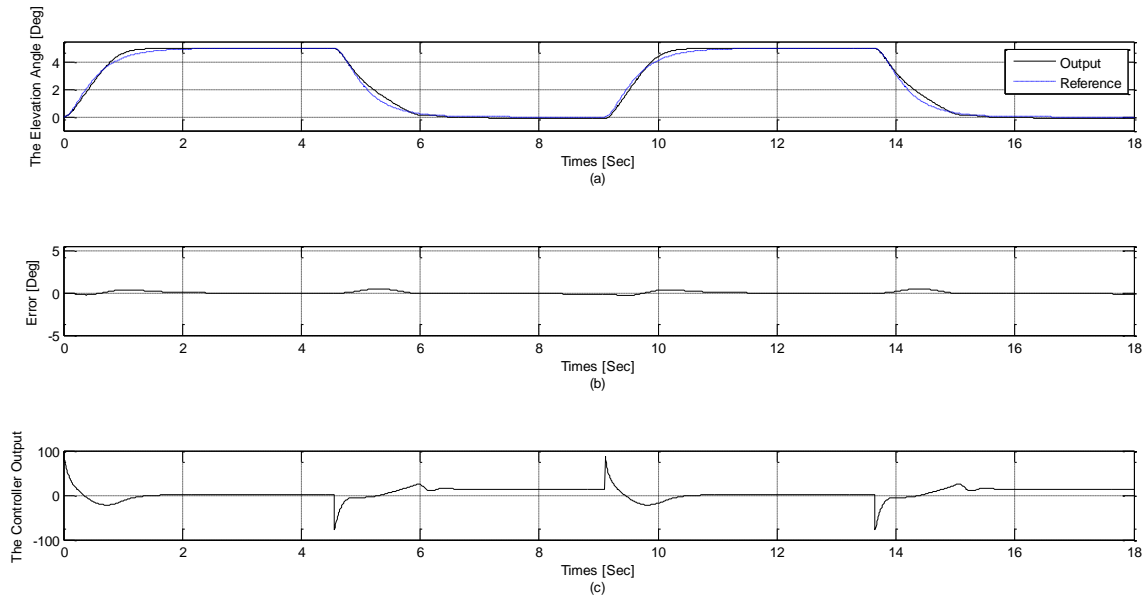


Fig. 5 (a) The Helicopter elevation angle. (b) The output tracking error. (c) Controller output.

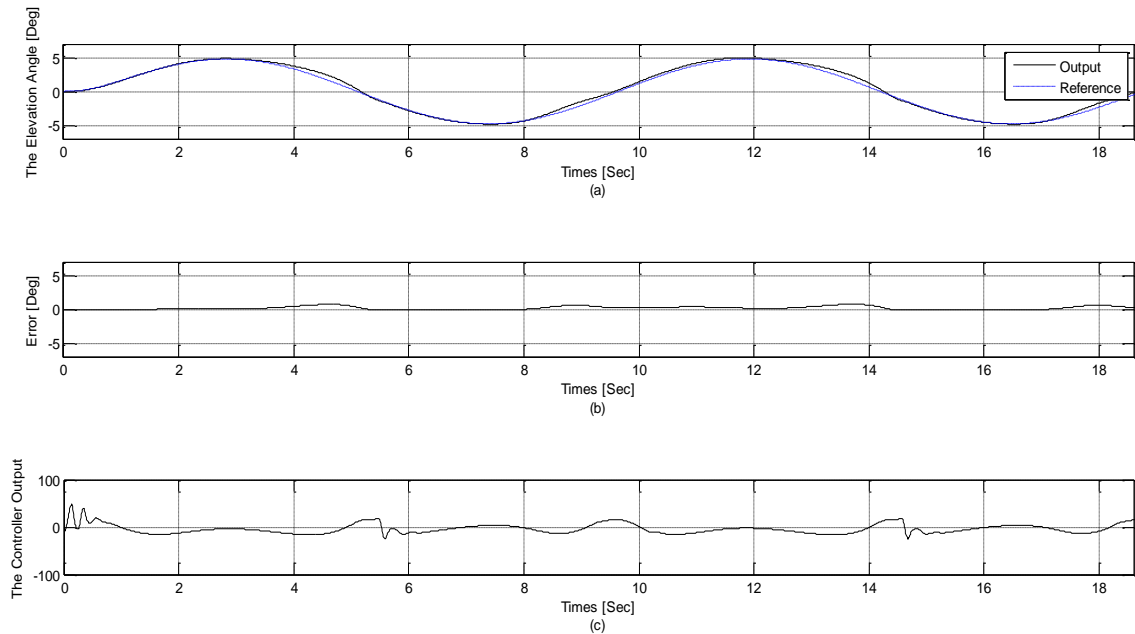


Fig. 6 (a) The Helicopter elevation angle. (b) The output tracking error. (c) Controller output.

V. CONCLUSION

A neural network-based model reference adaptive controller (NN MRAC) was proposed for controlling the elevation angle of a bench-top helicopter from Quanser Inc. The RBF neural network has been adaptively learned the helicopter uncertainty and nonlinear dynamics, then its output used as a part in the control law to compensate the system nonlinearity. Including Lyapunov stability theory in designing the RBF NN and selecting the optimal weights, enables the use of the proposed control law and ensures stability and robustness of the hovering system. Simulation results show that the proposed NN MRAC can efficiently solve the helicopter elevation angle problem.

References

- [1] X. Zhao, J. Han and Z. Wu, “Robust H_2 control with adaptive compensation input with application to yaw control of RUAVs,” in Proc. IEEE Conf. Ind. Electron, Soc. Nov. 2008, pp. 335-359.
- [2] A. T. Kutay, A. J. Calise, M. Idan and N. Hovakimyan, “Experimental results on adaptive output feedback control using a laboratory model helicopter,” IEEE Trans. Control Syst. Technol., Vol. 13, no. 2, pp. 196-202, Mar. 2005.
- [3] J. P. Su, W. J. Lu, “Composite sliding mode control and its application to a twin-rotor multi-input multi-output system”, AASRC Transactions of the Aeronautical and Astronautical Society of the R.O.C., pp. 275-282, 2001.
- [4] S. Bouabdalla and R. Siegwart, “Backstepping and sliding techniques applied to an indoor micro quadrotor”, Proceedings of IEEE International Conference on Robotics and Automation, : 2247-2252, 2005.
- [5] W.N. Gao and Z. Fang, “Adaptive Integral Backstepping Control for 3-DOF Helicopter”, Proceeding of the IEEE International Conference on Information and Automation Shenyang, China, June 2012.
- [6] Z. Fang and W. Gao, “Adaptive Integral Backstepping Control for a micro-quadrotor”, in Proceedings of the 2nd International Conference on Intelligent Control and Information Processing, pp. 910-915, 2011.
- [7] D. Cabecinhas, R. Cunha and C. Silvestre, “A nonlinear quadrotor trajectory tracking controller with disturbance rejection”, Control Engineering Practice, 16: 1-10, 2014
- [8] B. Zheng and Y. Zhong, “Robust Attitude Regulation of a 3-DOF Helicopter Benchmark: Theory and Experiments”, IEEE Transactions on Industrial Electronics, Vol. 58, No. 2, Feb. 2011.
- [9] M. Mehndiratta, E. Kayacan and T. Kumbasar, “Design and Experimental Validation of Single Input Type-2 Fuzzy PID Controllers as Applied to 3 DOF Helicopter testbed”, IEEE, 2016.
- [10] Quanser 3-DOF helicopter reference manual
- [11] A. H. Zaeri, S. B. Noor, M. M. Isa and F. S. Taip, “Design of Integral Augmented Sliding Mode Control for Pitch Angle of a 3-DOF Bench-top Helicopter”, Majlesi Journal of Electrical Engineering, Vol. 4, No. 3, Sep. 2010.
- [12] J. Cheng, J. Yi and D. Zhao, “Neural Network Based Model Reference Adaptive Control for Ship Steering System”, International Journal of Information Technology, Vol. 11, No. 6, 2005.
- [13] P. A. Ioannou, P. V. Kokotovic, “Adaptive systems with reduced Models”, Berlin, Germany, Springer-Verlag, 1983.
- [14] I. Landau, “Adaptive control: The Model Reference Approach”, New Yourk, Marcel Dekker, 1979.
- [15] La Salle, J., Lefschetz, S., “Stability By Lyapunov: Direct Method With Applications”, New York, Academic, 1961.