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Design of Model Reference Adaptive Controller for an Unstable Helicopter System

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Abstract - This project presents the design of a Model Reference Adaptive Controller (MRAC) for an unstable Helicopter System to track the pitch rate command signal with minimum control effort in nominal condition and also in the presence of aerodynamic fault and aerodynamic uncertainty. In the conventional flight control systems, controller gains are scheduled to provide better performance. Neural Networks are used for identification, modeling and control of nonlinear system. The off-line trained neural controller to track the pitch rate for an unstable helicopter system is obtained. Quantitative performance measures like maximum absolute error, root mean square error and control effort are measured. Responses at nominal condition and fault conditions are simulated.

Key Words: Neural network, Helicopter System, Flight control system, neural controller.

1. INTRODUCTION

Traditional flight control system are designed using the linearized helicopter model at different operating conditions and the controller gains are scheduled to provide better performance. Gain Scheduling is one of the most popular nonlinear control design approach [1], [2] which has been widely and successfully applied in fields ranging from aerospace to process control. However it is difficult for the gain scheduling technique to provide the necessary tracking performance under severe uncertainty and fault conditions. Hence, adaptive nonlinear flight control schemes are used to overcome this difficulty. During the past decade, a large amount of research work has been carried out in neural control theory almost independent from adaptive nonlinear control research [3]. The concept of Neural Adaptive Flight Control is perhaps the most challenging because it is constructed with guaranteed stability that ensures peak performance of the aircraft [4]. Neural networks are used for identification, modeling and control [5], [6] of the nonlinear systems due to their approximation capabilities and inherent adaptive features. The feasibility of applying neural-network architectures for identification and control of nonlinear systems was first demonstrated through numerical studies in [7]. Among various adaptive control schemes, model reference adaptive control, dynamic inversion and feedback error learning controls are widely used [8-12]. In feedback error-learning scheme [13], the control architecture uses a conventional controller in the inner loop to stabilize the system dynamics and the neural controller acts as an aid to the conventional controller for compensating the nonlinearities. Under severe uncertainty and fault conditions, the neural network is adapted to ensure better tracking performance, but the control effort required is usually high when compared to the adaptive neural controllers [14]. To overcome these problem, MRAC scheme is used, which track the pitch rate command signal.

The paper is organized as follows: In section 2.1, modeling of the nonlinear aircraft is discussed. In section 2.2, reference model used is described. In section 2.3, the model reference adaptive method used for the unstable helicopter system is discussed. Section 2.4 presents the simulation results obtained using the model reference adaptive system. Section 3 discusses the performance measures.

2.1 HELICOPTER SYSTEM MODELING

The Helicopter System is the Multiple Input Multiple Output and an unstable System with four inputs, five outputs and it has eight states. The nonlinear model of the helicopter system is given as

$$\dot{x} = f(x,u) \qquad (1)$$

where

$$x = [u\ v\ w\ p\ q\ r\ \phi\ \theta]^T \qquad (2)$$

represents the state variables and

$$u = [\delta_{col}\ \delta_{lat}\ \delta_{long}\ \delta_{dir}]^T \qquad (3)$$

represents the control vector

δ_{col} - collective input
δ_{lat} - lateral cyclic input
δ_{long} - longitudinal cyclic input
δ_{dir} - pedal input

The nonlinear model is linearized about the trim condition at hover, low speeds and straight and level flight at various speed conditions using analytical methods. The linearized helicopter system dynamics in the state space form is

$$\dot{X}(t) = AX(t) + Bu(t)$$
$$Y(t) = CX(t) + Du(t)$$

In order to obtain the set of linear equations which describes the longitudinal motion of the helicopter system, the nonlinear equations of motion are numerically perturbed around the trim conditions. In the state –space model, the perturbed states of the system (x) are forward speed v in m/s, angle of attack α in rad, pitch rate q in rad/s and pitch angle θ in rad. The input δ_{long} of the system is the pilot longitudinal cyclic deflection. The state space representations of the helicopter system are

When the helicopter system is operating at 25m/s cruise speed, the state space model is

$$A = \begin{bmatrix} -0.1688 & 0.8500 & 0 & -9.81 \\ -0.03 & -3.2797 & 0.9188 & 0 \\ 0 & 2.21 & -2.7546 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -0.4783 \\ -0.6178 \\ -3.2529 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 0 & 1 & 0 \end{bmatrix}$$

$$D = [0]$$

When the helicopter system is operating at 45m/s cruise speed, the state space model is

$$A = \begin{bmatrix} -2.026 & 1.224 & 0 & -9.81 \\ -0.03 & -3.9357 & 0.9188 & 0 \\ 0 & 3.1824 & -3.3055 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -0.6888 \\ -0.7414 \\ -4.6842 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 0 & 1 & 0 \end{bmatrix}$$

$$D = [0]$$

2.2 REFERENCE MODEL

For the helicopter system, the most commonly used reference model is the Attitude Command & Attitude Hold (ACAH) system. The reference model consists of a command filter. It is designed in such a way that its response satisfies handling qualities and is used to provide the desired response, when the input signal is applied to the helicopter system. The damping ratio of the filter is between 0.6 and 0.8 and the natural frequency is 5 rad/sec. The state space representation of the reference model is as follows:

$$A_{ref} = \begin{bmatrix} -3.5392 & -2.5088 \\ 2 & 0 \end{bmatrix}$$

$$B_{ref} = \begin{bmatrix} 2 \\ 0 \end{bmatrix}$$

$$C_{ref} = \begin{bmatrix} 0.8864 & 0.7664 \end{bmatrix}$$

$$D_{ref} = [0]$$

2.3 MODEL REFERENCE ADAPTIVE CONTROLLER

This is an adaptive control technique where the performance specifications are given in terms of a reference model. The reference model represents the ideal response of the process to a command signal. The neural model reference control architecture uses two neural networks: a controller network and a plant model network. The plant model is identified first, and then the controller is trained so that the plant output follows the reference model output. The system has an ordinary feedback loop composed of the process and the controller and another feedback loop that changes the controller parameters.

2.4 SIMULATION RESULTS

The data obtained by providing the pseudo random reference inputs are used to adapt the neural controller weight matrices off-line. From Fig. 1, it is observed that the controller parameters adapts such that they follow the reference command accurately.

A. *Responses under Nominal Condition*

Response for NN Model Reference Control is shown in Fig.2. Fig.3 shows the Longitudinal Cyclic Deflections applied to the helicopter system. Fig.4 (a, b, c, d) shows the response of the helicopter system at 45m/s using the Model Reference Adaptive Controller. It is shown that the pitch rate of the helicopter system closely follows the reference input. The forward speed decreases with increase in time. The angle of attack and the pitch angle increases with increase in time.

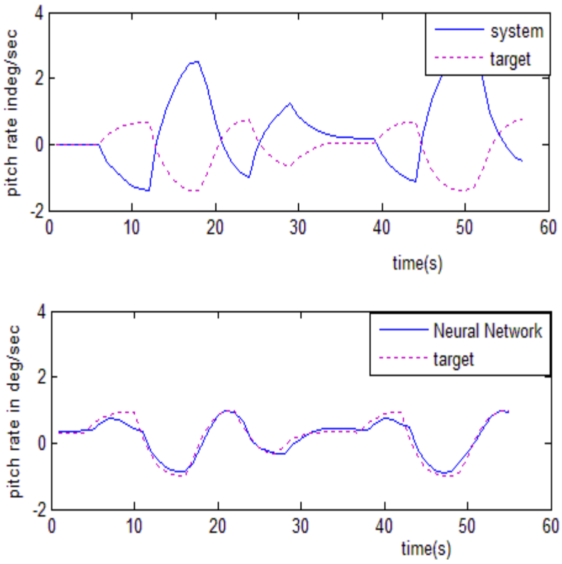


Fig -1: Response of the helicopter at nominal condition

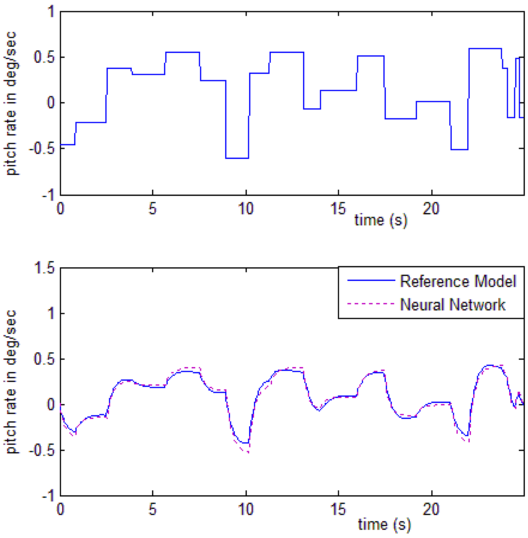


Fig -2: Response for NN Model Reference Control

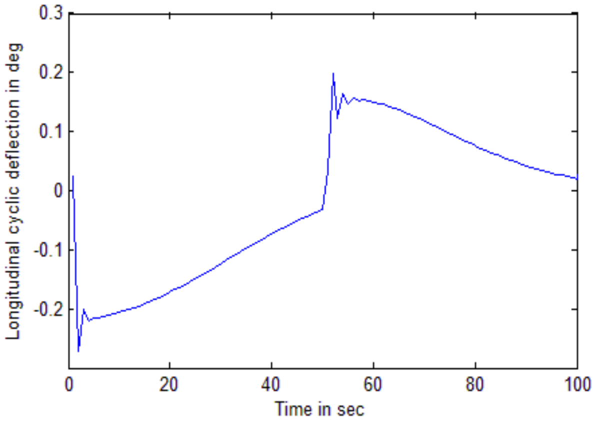
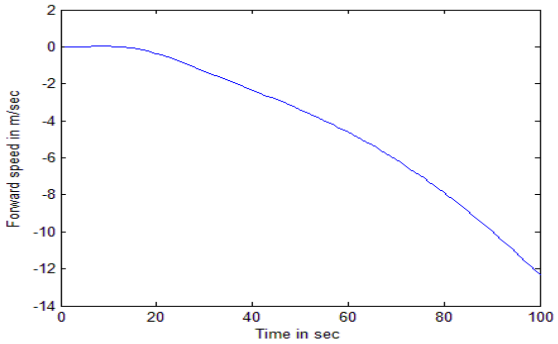
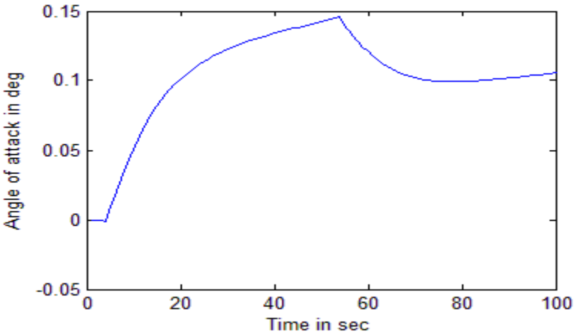


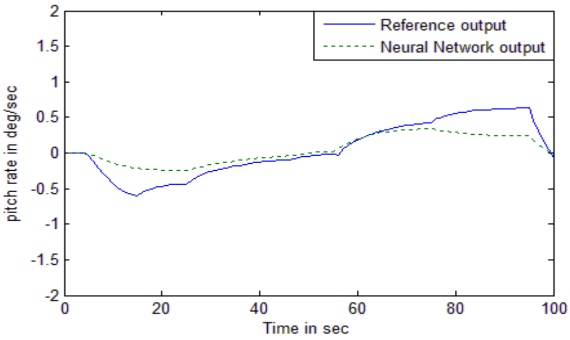
Fig -3: Longitudinal Cyclic Deflections



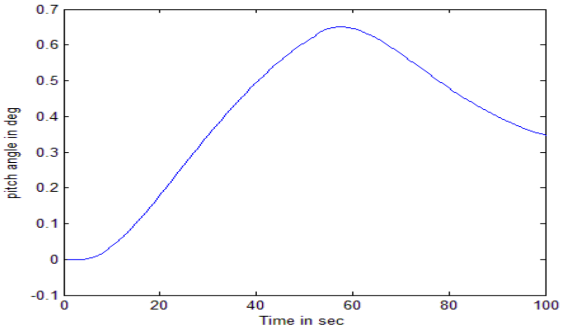
(a)



(b)



(c)



(d)

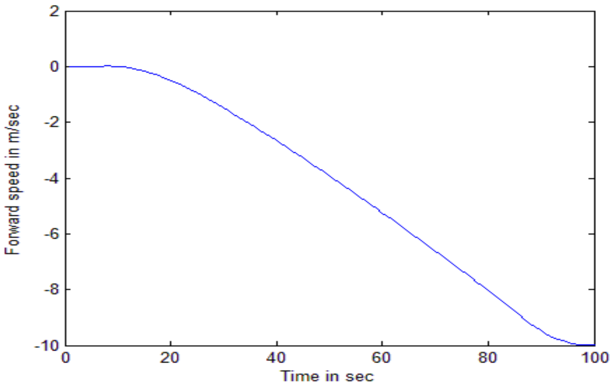
Fig -4: Response of the helicopter system at 45 m/s (a) forward speed (b) angle of attack (c) pitch rate (d) pitch angle

B. Responses under Fault Conditions

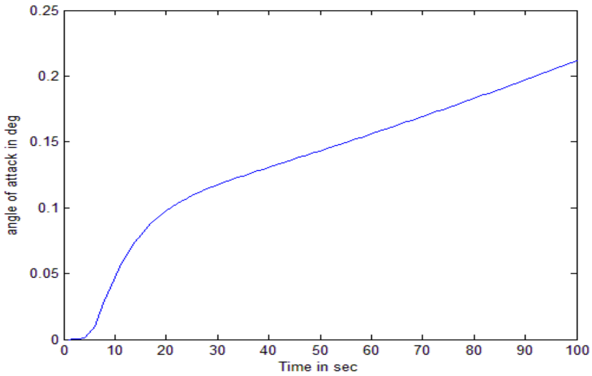
The responses of the helicopter system are observed under different fault conditions.

System Matrix Uncertainty (SMU): Here the ‘A’ matrix of the nominal helicopter system is assumed to vary by 150% (A’=1.5A). Now the controller will be tested with the same input signal and the responses are obtained. Fig. 5 (a, b) shows the response of the helicopter system under SMU fault at 45m/s.

Control Surface Loss (CSL): By varying the ‘*B*’ matrix of the nominal helicopter system by 50% (*B’=0.5A*) this fault is obtained. Now the controller will be tested with the same input signal and the responses are obtained. Fig. 6 (a, b) shows the response of the helicopter system under CSL fault at 45m/s.

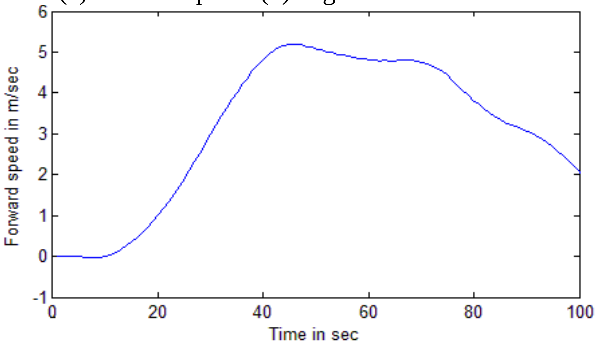


(a)

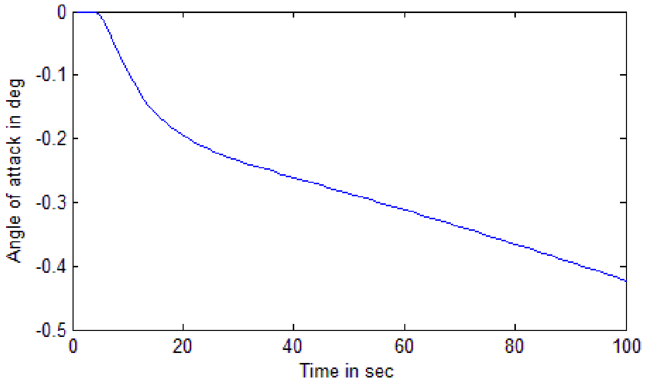


(b)

Fig -5: Response of the helicopter system under SMU fault at 45m/s (a) forward speed (b) angle of attack



(a)

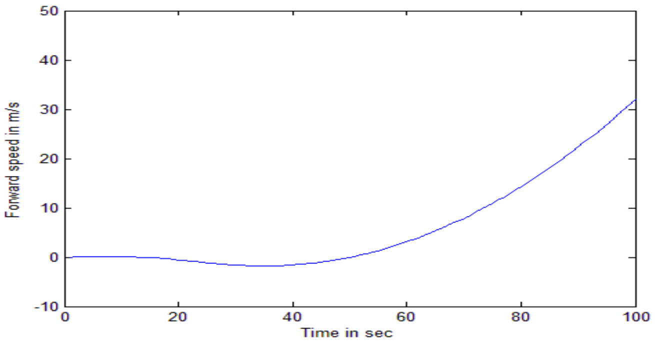


(b)

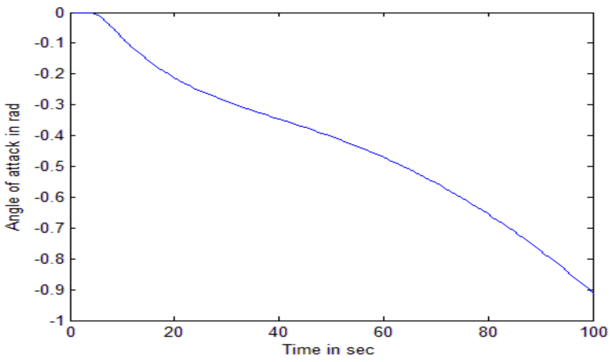
Fig -6: Response of the helicopter system under CSL fault at 45m/s (a) forward speed (b) angle of attack

C. Responses of the system at 25 m/s

Fig.7 (a, b) shows the response of the helicopter system at 25m/s using the Model Reference Adaptive Control System. The forward speed increases with increase in time and the angle of attack decreases with increase in time.



(a)



(b)

Fig -7: Response of the helicopter system at 25 m/s (a) forward speed (b) angle of attack.

2.5 PERFORMANCE MEASURES

The quantitative performance measures are maximum absolute error (MAE), root mean square error (RMSE) and maximum absolute elevator deflection (MEL) are calculated using these formulas.

MAE= $\max|y^{*}(k)-y(k)|$ (5)

RMSE= $\sqrt{\frac{1}{N}\sum_{k=1}^{N}[y^{*}(k)-y(k)]^{2}}$ (6)

MEL= $\max|\delta_{long}(k)|$ (7)

Table -1: Performance Measures for Controller at Different Flight Conditions

Speed, V (m/s)	Condition	MAE (˚/s)	RMSE (˚/s)	MEL (deg)	Control effort (deg)
45	Nominal	0.1438	0.01004	0.5	17.711
	SMU A=1.5A	0.1746	0.012	0.494	26.5
	CSL B=0.5B	0.22	0.015	0.453	26.698
25	Nominal	1.794	0.153	0.743	57.761
	SMU A=1.5A	0.6098	0.4616	0.981	104.38
	CSL B=0.5B	0.3800	0.0265	0.997	124.88

3. CONCLUSIONS

The neural network based Model Reference Adaptive controller for an unstable helicopter system is presented. The Model Reference Neural Controller is used to stabilize the helicopter system and track the pitch rate command signal. From the table, it is seen that the performance measures at different flight conditions are minimum so that the pitch rate tracks the reference signal closely. The performance measure MAE ranges from 0.1438 to 1.794 and RMSE ranges from 0.01004 to 0.4616. This guarantees a good tracking performance.

REFERENCES

1. Apkarian, P., Gahinet, P., Becker, G., Self-scheduled H1 control of linear parameter-varying systems: a design example .Automatica 31(9), 1251–1261, 1995.
2. Leith, D.J., Leithead, W.E., Survey of gain-scheduling analysis and design. International Journal of Control 73(11), 1001–1025, 2000.
3. Lingz hong Guo, Chris Melhuish, and Quanmin Zhu, Towards neural adaptive hovering control of helicopters, IEEE International Conference on Control Applications, 2002.
4. Orna Raz. "Validation of Online Artificial Neural Networks (ANNs)-An Informal Classification of Related Approaches". Technical Report for NASA Ames Research Center, Moffet Field, CA, 2000.
5. Peng, H., Yang, Z.J., Gui, W., Wu, M., Shioya, H., Nakano, K., Nonlinear system modelling and robust predictive control based on RBF-ARX model. Engineering Applications of Artificial Intelligence 20 (1), 1–9, 2007.
6. Uraikul, V., Chan, C.W., Tontiwachwuthikul, P., Artificial intelligence for monitoring and supervisory control of process systems. Engineering Applications of Artificial Intelligence 20 (2), 115–131, 2007.
7. K. Funahashi, "On the Approximate Realization of Continuous Mappings by Neural Networks," Neural Networks, Vol. 2, pp. 183-192, 1989.
8. Narendra, K.S., Neural networks for control: theory and practice. Proceedings of the IEEE 84(10), 1385–1406, 1996.
9. Narendra, K.S., Mukhopadhyay, S., Intelligent control using neural networks. IEEE Control Systems Magazine, 11–18, 1992.
10. Narendra, K.S., Parthasarathy, K., Identification and control of dynamical system using neural networks. IEEE Transactions on Neural Networks 1(1), 4–27, 1990.
11. Ng, G.W., Application of Neural Networks to Adaptive Control of Nonlinear Systems. Research Studies Press, Tauton, UK, 1997.
12. Polycarpou, M.M., Stable adaptive neural control scheme for nonlinear systems. IEEE Transactions on Automatic Control 41 (3), 447–451, 1996.
13. Li, Y., Sundararajan, N., Sarachandran, P., Stable neuro flight controller using fully tuned radial basis function neural networks. Journal of Guidance, Control and Dynamics24 (4), 665-674, 2001.
14. Sundaram Suresh, "Adaptive Neural Flight Control System for Helicopter", 2009.