Adaptive Fuzzy Output Feedback Control for the Nonlinear Heating, Ventilating, and Air Conditioning System

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Abstract: Heating, Ventilating and Air Conditioning (HVAC) system is a nonlinear MIMO system which is very difficult to control. This paper presents adaptive fuzzy output feedback control based on observer for nonlinear HVAC System whose state variables are not available. Fuzzy systems are employed to approximate the unknown nonlinear functions of the HVAC system and the state observer is designed for estimating the state variables of the HVAC system. In order to overcome the controller singularity problem, in addition, the new adaptive fuzzy output feedback controller is applied to the HVAC system. The obtained control system shows robustness and effectiveness compared with a classical feedback controller.

1. Introduction

In this paper, we design an adaptive fuzzy output feedback controller based on observer for unavailable state variables of the MIMO HVAC system. The adaptive fuzzy logic systems for the system is used to approximate the unknown functions and then using the "dominant input" concept of [6]. The state observer is constructed, upon which the adaptive fuzzy output feedback control system can be developed to control the MIMO HVAC system, and maintains the system stability to track set-point.

Section 2 will introduce a state space model with actuator dynamics. In section 3, we will present the feedback linearization technique with dynamic extension algorithm. Adaptive fuzzy output feedback control based on observer will be introduced for the unavailable state variables of HVAC system in section 4. In section 5, simulation results of the adaptive fuzzy output feedback control method will be given. Finally, section 6 will give some concluding remarks.

2. HVAC System

The state variable form of the dynamic HVAC equation [1] for the HVAC system can be rewritten as

$$\begin{aligned}
\dot{z_1} &= u_1\alpha_1(z_3 - z_1) - u_1\alpha_2(W_s - z_2) + \alpha_3(Q_0 - h_{fg}M_o)\\
\dot{z_2} &= u_1\alpha_1(W_s - z_2) + \alpha_4 M_o \\
\dot{z_3} &= u_1\beta_1(z_1 - z_3) + (1-\mu)u_1\beta_1(T_0 - z_1) - u_1\beta_3\big((1-\mu)W_0 + ux_2 - W_s\big) - 6000u_2\beta_2)
\end{aligned} \quad (1)$$

where
$u_1 = f_r, u_2 = gpm, z_1 = T_3, z_2 = W_3,\ z_3 = T_2, \alpha_1 = \frac{60}{V_s}$, $\alpha_2 = \frac{60h_{fg}}{c_p V_s}, \alpha_3 = \frac{1}{(1-\mu)\rho_a c_p V_s}, \alpha_4 = \frac{60}{\rho_a V_s}, \beta_1 = \frac{60}{V_{he}},\ \beta_2 = \frac{1}{\rho_a c_p V_{he}}, \beta_3 = \frac{60h_w}{c_p V_{he}}$.

In addition, the control input signal in this model is implemented to liquid valves and as described in [8], namely valve dynamic model can consider as

$$u_1 = \frac{k_1}{1+\tau_1 s}v_1, u_2 = \frac{k_2}{1+\tau_2 s}v_2$$

where k_1, k_2, τ_1 and τ_2 are the actuator's gain and time constant. $u = [u_1 \quad u_2]^T$ is the control signal applied and $v = [v_1 \quad v_2]^T$ is the input signal applied to the actuator. Therefore, we derive an augmented state space model with the new state vector as $z = [z_1 \quad z_2 \quad z_3 \quad u_1 \quad u_2]^T = [z_1 \quad z_2 \quad z_3 \quad z_4 \quad z_5]^T$.

The system model (1) becomes

$$\dot{z} = f(z) + g(z)v = \begin{bmatrix} a_1(z)\\ a_2(z)\\ a_3(z)\\ a_4(z)\\ a_5(z)\end{bmatrix} + \begin{bmatrix} 0 & 0\\ 0 & 0\\ 0 & 0\\ \frac{k_1}{\tau_1} & 0\\ 0 & \frac{k_2}{\tau_2}\end{bmatrix} v \quad (2)$$
$$y = [z_1 \quad z_2]^T$$

where
$a_1(z) = [\alpha_1(z_3 - z_1) - \alpha_2(W_s - z_2)]u_1 + \alpha_3(Q_0 - h_{fg}M_0) := \gamma_1 u_1 + \alpha_3(Q_0 - h_{fg}M_0)$, $a_2(z) = \alpha_1(W_s - z_2)u_1 + \alpha_4 M_0 := \gamma_2 u_1 + \alpha_4 M_0$, $a_3(z) = [\beta_1(z_1 - z_3) + (1-\mu)\beta_1(T_0 - z_1)]u_1 + [-\beta_3((1-\mu)W_0 + uz_2 - W_s)]u_1 - [6000\beta_2]u_2 := \gamma_3 u_1 + \gamma_4 u_2$, $a_4(z) = -\frac{u_1}{\tau_1}$, $a_5(z) = -\frac{u_2}{\tau_2}$.

3. Feedback Linearization for nonlinear HVAC system

We apply the feedback linearization technique to the an augumented state space model (2) to tracking the desired temperature and humidity ratio. We differentiate the outputs z_1 and z_2 until the inputs appear to reduce the nonlinear system to an aggregate indepentdent SISO channels called the noninteracting control problem. The HVAC system (2) has the relative degree $r = \{2,2\}$ [7]. The relative degree leads to

$$\begin{aligned}
z_1^{(2)} &= L_f^2 h_1 + L_{g_1}L_f h_1 v_1 + L_{g_2}L_f h_1 v_2\\
z_2^{(2)} &= L_f^2 h_2 + L_{g_1}L_f h_2 v_1 + L_{g_2}L_f h_2 v_2
\end{aligned} \quad (3)$$

However, $\begin{bmatrix} L_{g_1}L_f h_1 & L_{g_2}L_f h_1\\ L_{g_1}L_f h_2 & L_{g_2}L_f h_2\end{bmatrix} = \begin{bmatrix} \gamma_1 k_1/\tau_1 & 0\\ \gamma_2 k_2/\tau_2 & 0\end{bmatrix}$ is the decoupling matrix with singular. To achieve the relative degree and noninteracting control, we employ the dynamic extension for incorporating the dynamic state feedback into the HVAC system [9].

We set $v_1 = \varphi_1$, $\dot{\varphi}_1 = \varepsilon_1$ and $v_2 = \varphi_2$. The new augmented state variables are defined as $\bar{z} = [z, v_1]^T \in R^6$ and the HVAC system will be composed as

$$\dot{\bar{z}} = \bar{f}(\bar{z}) + \bar{g}_1(\bar{z})\varphi_1 + \bar{g}_2(\bar{z})\varphi_2 = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 + \dfrac{k_1 z_2}{\tau_2} \\ a_5 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \dfrac{k_2}{\tau_2} \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \varphi_1 \\ \varphi_2 \end{bmatrix} \tag{4}$$

Following the procedure of linearization for system (4), new linearizing state variables and output are defined as follows ;

$$x = \begin{bmatrix} x_1 \\ x_1^{(1)} \\ x_1^{(2)} \\ x_2 \\ x_2^{(1)} \\ x_2^{(2)} \end{bmatrix} = \begin{bmatrix} z_1 \\ a_1 \\ j_1 \\ z_2 \\ a_2 \\ -\alpha_1 z_4 a_2 + \alpha_1 (W_s - z_2) a_4 \end{bmatrix} \tag{5}$$

$$j_1 = -\alpha_1 z_4 a_1 + \alpha_2 z_4 a_2 + \alpha_1 z_4 a_3 + \{\alpha_1(z_3 - z_1) - \alpha_2(W_s - z_2)\} a_4$$

$$y = [x_1 \quad x_2]^T$$

where the vector relative degree $\bar{r} = \{3,3\}$. By using the new variables, system (4) can be rewritten as

$$\begin{aligned} x_1^{(3)} &= f_1(x) + g_{11}(x)\varphi_1 + g_{12}(x)\varphi_2 \\ &= L_{\bar{f}}^3 h_1 + L_{\bar{g}_1} L_{\bar{f}}^2 h_1 \varphi_1 + L_{\bar{g}_2} L_{\bar{f}}^2 h_1 \varphi_2 \\ x_2^{(3)} &= f_2(x) + g_{21}(x)\varphi_1 + g_{22}(x)\varphi_2 \\ &= L_{\bar{f}}^3 h_2 + L_{\bar{g}_1} L_{\bar{f}}^2 h_2 \varphi_1 + L_{\bar{g}_2} L_{\bar{f}}^2 h_2 \varphi_2 \end{aligned} \tag{6}$$

Equation (6) is equivalent to the following system

$$\begin{aligned} \dot{x} &= Ax + B[F(x) + G(X)\varphi] \\ y &= [x_1 \quad x_2]^T \end{aligned} \tag{7}$$

where

$F(x) = [f_1 \; f_2]^T$, $G(x) = \begin{bmatrix} g_{11} & g_{21} \\ g_{21} & g_{22} \end{bmatrix}$, and $A = diag\left(\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}, \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}\right)$, $B = diag\left(\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}\right)$, $C = diag([1 \quad 0 \quad 0], [1 \quad 0 \quad 0])$.

For the given set point references y_{1m} and y_{2m}, we define the tracking errors as $e_1 = y_1 - y_{1m}$ and $e_2 = y_2 - y_{2m}$ and denote as

$$E = [e_1 \quad e_2]^T \tag{8}$$

$$y_m = [y_{1m} \quad y_{2m}]^T \tag{9}$$

$$y_m^{(3)} = [y_{1m}^{(3)} \quad y_{2m}^{(3)}]^T \tag{10}$$

and

$$Y_m = [y_{1m} \quad y_{1m}^{(1)} \quad y_{1m}^{(2)} \quad y_{2m} \quad y_{2m}^{(1)} \quad y_{2m}^{(2)}]^T \tag{11}$$

We obtain the error matrix

$$e = Y_m - x = [e_1 \quad e_1^{(1)} \quad e_1^{(2)} \quad e_2 \quad e_2^{(1)} \quad e_2^{(2)}]^T \tag{12}$$

When the linearizing control law for HVAC system is designed as

$$\varphi = G^{-1}\left(-F + y_m^{(3)} - Ke\right) \tag{13}$$

with the $K = diag([k_{11} \quad k_{12} \quad k_{13}], [k_{21} \quad k_{22} \quad k_{23}])$ chosen so that the polynomial $s^3 + k_{i1}s^2 + k_{i2}s + k_{i3} = 0$, i=1, 2 has all their roots stricktly in the left-half complex plane, leads to meet the desired performance specification such as transient response or steady state error.

4. Adaptive Fuzzy Output Feedback Control

The general fuzzy logic systems with singleton fuzzifier, product inference and center-average defuzzifier is designed as

$$f(z) = \frac{\sum_{l=1}^{M} y^l \left[\prod_{i=1}^{N} u_{A_i^l}(x_i)\right]}{\sum_{l=1}^{M} \left[\prod_{i=1}^{N} u_{A_i^l}(x_i)\right]} \tag{14}$$

based on the lth fuzzy IF-THEN rule

R^l : if x_1 is A_1^l, x_2 is A_2^l, then y is B^l.

where A_1^l, A_2^l, ... , A_1^l and B^l are fuzzy sets. M is the number of the fuzzy rules, and y^l is the point at which $u_{B^l}(\bar{y}^l) = 1$.

MIMO fuzzy logic systems $\hat{F}(\hat{x}|\theta_1)$ and $\hat{G}(\hat{x}|\theta_2)$ based on observer are of the form

$$\hat{F}(\hat{x}|\Theta_1) = \Phi(\hat{x})\Theta_1, \; \hat{G}(\hat{x}|\theta_2) = \Phi(\hat{x})\Theta_2 \tag{15}$$

where Θ_1 and Θ_2 are parameter vectors and $\Phi(\hat{x}) = diag[\xi^T, \xi^T]$ is a regressive vector.

Since we assume that the state variables for the HVAC system are unavailable for measurement, the state x and the error e replace their estimates $\hat{x}$ and $\hat{e} = Y_m - \hat{x}$. Design the fuzzy adaptive observer for estimates $\hat{x}$ as follows :

$$\begin{aligned} \dot{\hat{x}} &= A\hat{x} + B[\hat{F}(\hat{x}|\Theta_1) + \hat{G}(\hat{x}|\theta_2)\varphi \\ &\quad - u_a - u_b - u_s] + K_o(y - C^T\hat{x}) \\ \hat{y} &= C^T\hat{x} \end{aligned} \tag{16}$$

where K_o is the observer gain matrix to guarantee the characteristic polynomial $A - K_o C^T$ to be Hurwitz, u_a is a H^∞ robust control to attenuate the disturbance effect on system outputs, u_b is the feedback control for ê and u_s is a sliding-mode control to compensate fuzzy approximation errors.

Define the observation error as $\tilde{e} = e - \hat{e}$ and $\tilde{y} = y - \hat{y}$ and subtracting (16) from (7) results in

$$\begin{aligned}\dot{\tilde{e}} &= (A - K_oC^T)\tilde{e} + B\Big[\big(F(x) - \hat{F}(\hat{x}|\Theta_1)\big) + \\ &\big(G(x) - \hat{G}(\hat{x}|\theta_2)\big)\varphi + u_a + u_b + u_s\Big] \\ \tilde{y} &= C^T\tilde{e}\end{aligned} \tag{17}$$

It is assumed that x, $\hat{x}$, Θ_1 and θ_2 belong to compact sets U_x, $U_{\hat{x}}$, Ω_{Θ_1} and Ω_{θ_2}, respectively, which are defined as

$$\begin{aligned}U_x &= \{x \in R^n : \|x\| \le M_x\} \\ U_{\hat{x}} &= \{\hat{x} \in R^n : \|\hat{x}\| \le M_{\hat{x}}\}\end{aligned} \tag{18}$$

$$\begin{aligned}\Omega_{\Theta_1} &= \{\Theta_1 \in R^l : \|\Theta_1\| \le M_{\Theta_1}\} \\ \Omega_{\theta_2} &= \{\theta_2 \in R^l : \|\theta_2\| \le M_{\theta_2}\}\end{aligned} \tag{19}$$

where M_x, $M_{\hat{x}}$, M_{Θ_1} and M_{θ_2} are the designed parameters, and l is the number of fuzzy inference rules.

Define the optimal parameter vector Θ_1^* and Θ_2^*

$$\begin{aligned}\Theta_1^* &= arg\, min_{\Theta_1 \in \Omega_{\Theta_1}}\{sup_{x \in U_x, \hat{x} \in U_{\hat{x}}}|F(x) - \hat{F}(\hat{x}|\Theta_1)|\} \\ \Theta_2^* &= arg\, min_{\Theta_2 \in \Omega_{\Theta_2}}\{sup_{x \in U_x, \hat{x} \in U_{\hat{x}}}|G(x) - \hat{G}(\hat{x}|\Theta_2)|\}\end{aligned} \tag{20}$$

and fuzzy approximation error as

$$\begin{aligned}w &= \big(\hat{F}(\hat{x}|\Theta_1^*) - \hat{F}(x|\Theta_1^*)\big) + \big(\hat{F}(x|\Theta_1^*) - F(x)\big) \\ &+ \Big[\big(\hat{G}(\hat{x}|\Theta_2^*) - \hat{G}(x|\Theta_2^*)\big) + \big(\hat{G}(x|\Theta_2^*) - G(x)\big)\Big]\varphi = \bar{F}(\hat{x}) + \bar{F}(x) + \big(\bar{G}(\hat{x}) + \bar{G}(x)\big)\varphi\end{aligned} \tag{21}$$

Then, the error dynamic (17) can be formulated as

$$\begin{aligned}\dot{\tilde{e}} &= (A - K_oC^T)\tilde{e} + B[\big(\hat{F}(\hat{x}|\Theta_1) - \hat{F}(\hat{x}|\Theta_1^*)\big) \\ &+ \big(\hat{G}(\hat{x}|\theta_2) - \hat{G}(\hat{x}|\Theta_2^*)\big)\varphi + u_a + u_b + u_s + w] \\ \tilde{y} &= C^T\tilde{e}\end{aligned} \tag{22}$$

According to (17) and (20), (22) can be expressed as

$$\begin{aligned}\dot{\tilde{e}} &= (A - K_oC^T)\tilde{e} + B[\Phi(\hat{x})\tilde{\Theta}_1 + \Phi(\hat{x})\tilde{\Theta}_2\varphi \\ &+ u_a + u_b + u_s + w] \\ \tilde{y} &= C^T\tilde{e}\end{aligned} \tag{23}$$

where $\tilde{\Theta}_1 = \Theta_1 - \Theta_1^*$ and $\tilde{\Theta}_2 = \Theta_2 - \Theta_2^*$.

Remark 1. There exist positive-definite solutions P_1 and P_2 in the following Lyapunov Equation and Riccati Equation for the given positive-definite matrices Q_1 and Q_2 [13].

According to Remark 1, the adaptive fuzzy output feedback controller is designed as

$$\begin{aligned}\varphi = \hat{G}(\hat{x}|\theta_2)^+[-\hat{F}(\hat{x}|\Theta_1) + y_m^{(3)} + K_c^T\hat{e} \\ + u_a + u_b + u_s]\end{aligned} \tag{24}$$

where K_c^T is the feedback control gain vector to make the characteristic polynomial of $A - BK_c^T$ to be Hurwitz. Since the estimated matrix $\hat{G}(\hat{x}|\theta_2)$ is singular, $\hat{G}(\hat{x}|\theta_2)^{-1}$ is not well-defined. In order to overcome this problem, $\hat{G}(\hat{x}|\theta_2)^+$ is the regular inverse of $\hat{G}(\hat{x}|\theta_2)$ defined as

$$\begin{aligned}\hat{G}(\hat{x}|\theta_2)^+ = \hat{G}(\hat{x}|\theta_2)^T[\varepsilon_0 I + \hat{G}(\hat{x}|\theta_2)\hat{G}(\hat{x}|\theta_2)^T]^{-1}, \\ \varepsilon_0 > 0\end{aligned} \tag{25}$$

Since $P_2B = C$ and $\tilde{e}$ is measurable, the control law as

$$\begin{aligned}u_a &= -\tfrac{1}{2}R^{-1}B^TP_2\tilde{e} = -\tfrac{1}{2}R^{-1}C^T\tilde{e} \\ u_b &= -K_o^TP_1\hat{e} \\ u_s &= -ksgn(B^TP_2\tilde{e}) = -ksgn(C^T\tilde{e})\end{aligned} \tag{26}$$

with $k > 0$ as a sliding gain to be determined.

The parameter vector adaptive adjusting laws are chosen as

$$\begin{aligned}\dot{\Theta}_1 &= -\gamma_1\Phi(\hat{x})^T(B^TP_2\tilde{e}) = -\gamma_1\Phi(\hat{x})^T(C^T\tilde{e}) \\ \dot{\Theta}_2 &= -\gamma_2\Phi(\hat{x})^T(B^TP_2\tilde{e}\varphi) = -\gamma_2\Phi(\hat{x})^T(C^T\tilde{e}\varphi)\end{aligned} \tag{27}$$

where $\gamma_1 > 0$ and $\gamma_2 > 0$ are two adaptation gains to be designed.

5. Simulation

We consider the continuous HVAC dynamics Eq. (9) for adaptive fuzzy output feedback control. The feedback and observer gain matrices are chosen as

$$K_c = diag([100 \quad 1000 \quad 10], [10 \quad 1000 \quad 100]),$$
$$K_o{}^T = diag([500000 \quad 15 \quad 7], [450000 \quad 10 \quad 9]).$$

In this simulation, z_1 and z_2 are used as the premise variables for the fuzzy system. When we define sixteen fuzzy rules to be of the following form :

$R^{(j)}$: If z_1 is F_1^j and z_1 is F_1^j, then y is G^j ($j = 1, 2, \cdots, 16$),

the membership functions for each variable are selected as follows :

$$\mu_{A_1^1}(z_1) = \begin{cases} 1 & z_1 < -30 \\ 1 - 2\left(\frac{z_1+30}{30}\right)^2 & -30 < z_1 < -15 \\ 2\left(\frac{z_1}{30}\right)^2 & -15 < z_1 < 0 \\ 0 & z_1 > 0 \end{cases},$$

$$\mu_{A_1^2}(z_1) = \frac{1}{e^{z_1{}^2/2*10^2}}, \quad \mu_{A_1^3}(z_1) = \frac{1}{e^{(z_1-30)^2/2*10^2}},$$

$$\mu_{A_1^4}(z_1) = \frac{1}{1 + e^{-35(z_1-65)}}$$

$$\mu_{A_1^1}(z_2) = \begin{cases} 1 & z_2 < -0.015 \\ 1 - 2\left(\frac{z_2+0.015}{0.015}\right)^2 & -0.015 < z_2 < -0.0075 \\ 2\left(\frac{z_2}{0.015}\right)^2 & -0.0075 < z_2 < 0 \\ 0 & z_2 > 0 \end{cases},$$

$$\mu_{A_2^2}(z_2) = \frac{1}{e^{{z_2}^2/_{2*0.001^2}}}, \mu_{A_2^3}(z_2) = \frac{1}{e^{(z_2-0.01)^2/_{2*0.001^2}}},$$
$$\mu_{A_2^4}(z_2) = \frac{1}{1+e^{-0.0075(z_2-0.00175)}}.$$

Since the initial premise variables are $T_3^0(0) = 85$ °F, $W_3^0(0) = 0.021$ lb/lb, $T_2^0(0) = 40$ °F, $u_1^0(0) = 4250$ cfm, $u_2^0(0) = 30$ gpm and $v_1^0(0) = 4250$, the initial new variables are $x_1(0) = 85$, $x_1^{(1)}(0) = 506.9701$, $x_1^{(2)}(0) = 8350305$, $x_2(0) = 0.021$, $x_2^{(1)}(0) = -0.0227$ and $x_2^{(2)}(0) = -30.4326$. In the section 4, constructing fuzzy systems $\hat{F}(\hat{x}|\theta_1)$ and $\hat{G}(\hat{x}|\theta_2)$, and by using observer (10), we obtain the estimated $\hat{x}$ and fuzzy systems $\hat{F}(\hat{x}|\theta_1)$ and $\hat{G}(\hat{x}|\theta_2)$. Adaptation adjusting factors are chosen as $\gamma_1 = 0.0001$ and $\gamma_2 = 0.00001$. The initial estimated values are chosen as

$$\hat{x}_1(0) = 80, \hat{x}_1^{(1)}(0) = 0, \hat{x}_1^{(2)}(0) = 0, \hat{x}_2(0) = 0.016,$$
$$\hat{x}_2^{(1)}(0) = 0, \hat{x}_2^{(2)}(0) = 0 \text{ and } \Theta_1(0) = 0, \Theta_2(0) = \mathrm{I}.$$

For the given $Q_1 = Q_2 = diag[I_{3\times3}, I_{3\times3}]$, two positive-definite matrices are solved from Remark 1.

$$P_1 = diag\left(\begin{bmatrix} 5.0056 & -0.5 & -0.1061 \\ -0.5 & 0.1061 & -0.5 \\ -0.1061 & -0.5 & 51.1111 \end{bmatrix}, \begin{bmatrix} 50.5501 & -0.5 & -0.06 \\ -0.5 & 0.06 & -0.5 \\ -0.06 & -0.5 & 5.011 \end{bmatrix}\right)$$

$$P_2 = diag\left(\begin{bmatrix} 0 & -0.0001 & -0.0003 \\ -0.0001 & 3.0795 & 4.2421 \\ -0.0003 & 4.2421 & 13.0658 \end{bmatrix}, \begin{bmatrix} 0 & -0.0002 & -0.0004 \\ -0.0002 & 3.0795 & 4.2420 \\ -0.0004 & 4.2420 & 13.0657 \end{bmatrix}\right)$$

We want to track the temperature and humidity ratio to their respecting the given set point references of 70 °F and 0.0088 lb/lb shown as Figure 1. The response of adaptive fuzzy output feedback control based on observer is better than feedback linearization approach.

6. Conclusions

In this paper, we apply an adaptive fuzzy output feedback control based on observer for an uncertain HVAC system with the unknown state variables. The state observer is first designed to estimate state variables via which fuzzy control schemes are formulated. The adaptive fuzzy output feedback controller tracks the desired temperature and humidity ratio. Simulations have proved that the adaptive fuzzy output feedback controller is superior to the classical feedback control.

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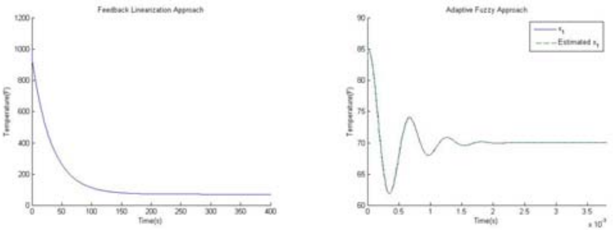
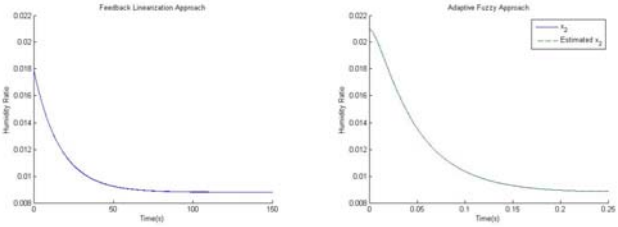
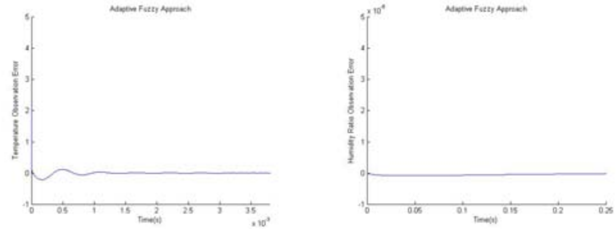


(a) Temperature
(Left : Feedback Linearization, Right : Adaptive Fuzzy Control)



(b) Humidity Ratio
(Left : Feedback Linearization, Right : Adaptive Fuzzy Control)



(c) Observation Error
(Left : Temperature, Right : Humidity Ration)
Figure 1. Responses for HVAC system

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