

基于观测器的模型不确定的耦合时空混沌 H_∞ 跟踪控制*

窦春霞 张淑清

(燕山大学电气工程学院, 秦皇岛 066004)

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考虑子系统的时空耦合作用及模型的不确定性, 实现模型不确定的耦合时空混沌的跟踪控制非常困难. 然而耦合时空混沌的每个子系统用一系列模糊逻辑模型逼近, 同时考虑子系统状态的不可测性, 采用模糊观测器来估计子系统的状态. 由于混沌模型的很多参数和动态特性很难准确地确定即模型具有不确定性, 因此在用模糊模型逼近的同时定会产生建模误差. 基于模糊模型及状态观测器, 考虑混沌模型的不确定性, 提出一种 H_∞ 模糊跟踪控制方法, 实现模型不确定性的耦合时空混沌的鲁棒跟踪控制. 将控制方案表征为求解线性矩阵不等式问题, 并用凸优化方法求解控制器参数, 确保系统的全局渐近稳定性. 仿真实验验证了所提方案的有效性.

关键词: 耦合时空混沌, 模糊模型, 模糊观测器, H_∞ 模糊跟踪控制, 线性矩阵不等式

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1. 引言

由于大规模非线性混沌系统的不断涌现, 对混沌系统控制提出了更高的要求和挑战, 更为复杂的混沌系统控制, 如时空混沌、超混沌的控制问题开始引起人们的关注. 有关超混沌控制的研究结果有所报道^[1-3], 而对时空混沌控制的研究报道不多. 混沌控制分为稳定控制和跟踪控制两种, 一般情况下跟踪控制要比稳定控制更加复杂. 由于外界因素的千变万化以及工作状态的日趋复杂, 很多混沌系统是由多个子系统时空耦合而成, 而且模型常常具有不确定性, 这给混沌控制带来很大的困难. 近年来的研究发现, 非线性混沌系统能很好地用 Takagi-Sugeno (T-S) 模糊线性模型逼近, 非线性混沌系统的模糊控制引起研究者的兴趣^[4-10]. 但用 T-S 模糊模型逼近模型不确定的混沌系统时, 定会在模糊模型和真实系统之间产生建模误差, 因此要实现该类混沌的跟踪控制, 必须计及建模误差的影响. 有关模型不确定的耦合时空混沌跟踪控制的相关报道就更少. 为此, 本文采用一系列 T-S 模糊逻辑模型逼近耦合时空混沌的每个子系统, 每个模糊逻辑模型代表

子系统在特定运行点的局部线性化模型, 同时考虑子系统状态的不可测性, 采用模糊观测器来估计子系统的状态. 基于具有观测器的子系统模糊模型, 计及模型的不确定性即建模误差, 提出一种 H_∞ 模糊跟踪控制方案, 并将该方案的状态反馈控制器表征为线性矩阵不等式 (LMI) 问题, 采用凸优化方法求解控制器的参数^[11-19]. 该方案能克服外界扰动, 确保模型不确定的耦合时空混沌系统的全局渐近稳定. 仿真实验验证了方案跟踪性能的有效性.

2. 模型不确定的耦合时空混沌的模糊模型

考虑由 n 个子系统组成的模型具有不确定性的耦合时空混沌

$$\begin{aligned} \dot{x}_i(t) &= f_i(X(t), u_i(t)) + \omega_i(t), \\ y_i(t) &= g_i(x_i(t)) + v_i(t), \end{aligned} \quad (1)$$

其中 $x_i(t) \in R^{n_i}$ 为第 i 个子系统状态向量, $u_i(t) \in R^{m_i}$ 为控制向量; $\omega_i(t)$, $y_i(t)$ 和 $v_i(t)$ 分别为外界扰动向量、输出向量和测量噪声向量, 且 $i = 1, 2, \dots, n$.

$$N = \sum_{i=1}^n n_i, \quad X(t) = (x_1^T(t), x_2^T(t), \dots, x_n^T(t))^T$$

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$\in R^N$; $f_i(\cdot)$ 和 $g_i(\cdot)$ 均为光滑的向量场.

基于(1)式模型不确定的耦合时空混沌设计全局稳定控制器很困难. 将耦合时空混沌的每个子系统表示成一系列局部线性化模型即 T-S 模糊模型, 该模型被描述成一组“如果-则”模糊规则.

$$\begin{aligned} R_p^k \text{ 如 } z_1(t) \text{ 为 } F_{k1} \dots z_g(t) \text{ 为 } F_{kg} \text{ 则} \\ \dot{x}_i(t) = A_{ik}X(t) + B_{ik}u_i(t) + \omega_i(t), \\ y_i(t) = C_{ik}x_i(t) + v_i(t), \end{aligned}$$

其中 $k=1, 2, \dots, l$ 为模糊规则数, $z_1(t), \dots, z_g(t)$ 为前提变量, F_{k1}, \dots, F_{kg} 为模糊集合, A_{ik}, B_{ik} 和 C_{ik} 为系数矩阵.

若模糊化采用单点模糊集合, 解模糊采用加权平均法, 则整个子系统模型为

$$\begin{aligned} \dot{x}_i(t) = \sum_{k=1}^l h_k(z(t)) [A_{ik}X(t) + B_{ik}u_i(t) \\ + \omega_i(t)], \\ y_i(t) = \sum_{k=1}^l h_k(z(t)) [C_{ik}x_i(t) + v_i(t)], \end{aligned}$$

其中

$$\begin{aligned} \mu_k(z(t)) = \prod_{j=1}^g F_{kj}(z_j(t)), \\ h_k(z(t)) = \mu_k(z(t)) / \sum_{k=1}^l \mu_k(z(t)). \end{aligned}$$

因 $\mu_k(z(t)) \geq 0$, 则 $h_k(z(t)) \geq 0$, 且 $\sum_{k=1}^l h_k(z(t)) = 1$.

考虑到子系统状态的不可测性, 设计子系统模糊状态观测器为

$$R_p^k \text{ 如 } z_1(t) \text{ 为 } F_{k1} \dots z_g(t) \text{ 为 } F_{kg} \text{ 则}$$

$$\dot{\hat{x}}_i(t) = A_{ik}\hat{X}(t) + B_{ik}u_i(t) + L_{ik}(y_i(t) - \hat{y}_i(t)),$$

其中 $\hat{y}_i(t) = C_{ik}\hat{x}_i(t)$, $\hat{x}_i(t)$, $\hat{y}_i(t)$ 和 L_{ik} 分别为第 i 个子系统状态观测器的状态估计向量、输出估计向量和增益矩阵.

解模糊得子系统状态观测器为

$$\begin{aligned} \dot{\hat{x}}_i(t) = \sum_{k=1}^l h_k(z(t)) [A_{ik}\hat{X}(t) + B_{ik}u_i(t) \\ + L_{ik}(y_i(t) - \hat{y}_i(t))]. \end{aligned}$$

若考虑模型的不确定性即建模误差, 子系统的 T-S 模糊模型可重写为

$$\begin{aligned} \dot{x}_i(t) = \sum_{k=1}^l h_k(z(t)) [A_{ik}X(t) + B_{ik}u_i(t) + \Delta f_i \\ + \omega_i(t)], \end{aligned}$$

$$y_i(t) = \sum_{k=1}^l h_k(z(t)) [C_{ik}x_i(t) + v_i(t)].$$

子系统的模糊观测器可重写为

$$\begin{aligned} \dot{\hat{x}}_i(t) = \sum_{k=1}^l h_k(z(t)) [A_{ik}\hat{X}(t) + B_{ik}u_i(t) \\ + \Delta f_i + L_{ik}(y_i(t) - \hat{y}_i(t))], \end{aligned}$$

其中 Δf_i 为第 i 个子系统的建模误差, 即

$$\begin{aligned} \Delta f_i = f_i(X(t), u_i(t)) - \sum_{k=1}^l h_k(z(t)) [A_{ik}X(t) \\ + B_{ik}u_i(t) + \omega_i(t)], \end{aligned}$$

且满足: $\|\Delta f_i\| \leq \alpha_i \|X(t)\|$, α_i 为大于零的常数.

若考虑建模误差则整体耦合时空混沌可表示为

$$\begin{aligned} \dot{X}(t) = \sum_{k=1}^l h_k(z(t)) [A_k X(t) + B_k u(t) \\ + \Delta f + \omega(t)], \end{aligned} \quad (2)$$

$$y(t) = \sum_{k=1}^l h_k(z(t)) [C_k X(t) + v(t)].$$

耦合时空混沌状态观测器可表示为

$$\begin{aligned} \dot{\hat{X}}(t) = \sum_{k=1}^l h_k(z(t)) [A_k \hat{X}(t) + B_k u(t) + \Delta f \\ + L_k(y(t) - \hat{y}(t))], \end{aligned} \quad (3)$$

其中

$$\begin{aligned} A_k &= (A_{1k}^T \dots A_{nk}^T)^T, \\ \Delta f &= (\Delta f_1^T \dots \Delta f_n^T)^T, \\ B_k &= \text{diag}(B_{ik}), \\ C_k &= \text{diag}(C_{ik}), \\ u(t) &= (u_1^T(t) \dots u_n^T(t))^T, \\ \omega(t) &= (\omega_1^T(t) \dots \omega_n^T(t))^T, \\ y(t) &= (y_1^T(t) \dots y_n^T(t))^T, \\ \hat{y}(t) &= (\hat{y}_1^T(t) \dots \hat{y}_n^T(t))^T, \\ v(t) &= (v_1^T(t) \dots v_n^T(t))^T, \\ L_k &= \text{diag}(L_{ik}). \end{aligned}$$

3. 模型不确定的耦合时空混沌的 H_∞ 跟踪控制

设参考模型为

$$\dot{X}_r(t) = A_r X_r(t) + r(t), \quad (4)$$

其中 $X_r(t) \in R^N$ 为参考向量, A_r 为渐近稳定系数矩阵, $r(t)$ 为有界参考输入向量.

设计模糊控制器为

R_p^k 如 $z_1(t)$ 为 F_{k1} ... $z_g(t)$ 为 F_{kg} 则

$$u(t) = K_k(\hat{X}(t) - X_r(t)).$$

解模糊得全局控制器为

$$u(t) = \sum_{k=1}^l h_k(z(t)) [K_k(\hat{X}(t) - X_r(t))]. \quad (5)$$

设状态估计误差为

$$e(t) = X(t) - \hat{X}(t). \quad (6)$$

由(2)(3)(6)式得

$$\begin{aligned} \dot{e}(t) &= \dot{X}(t) - \dot{\hat{X}}(t) \\ &= \sum_{k=1}^l \sum_{m=1}^l h_k(z(t)) h_m(z(t)) \\ &\quad \times [(A_k - L_k C_m) e(t) \\ &\quad + \omega(t) - L_k v(t)]. \end{aligned} \quad (7)$$

将(5)(6)式代入(2)式得

$$\begin{aligned} \dot{\hat{X}}(t) &= \sum_{k=1}^l \sum_{m=1}^l h_k(z(t)) h_m(z(t)) \\ &\quad \times [(A_k + B_k K_m) X(t) - B_k K_m X_r(t) \\ &\quad - B_k K_m e(t) + \Delta f + \omega(t)]. \end{aligned} \quad (8)$$

设计 H_∞ 跟踪性能指标为

$$\frac{\int_0^{t_f} [(X(t) - X_r(t))^T Q (X(t) - X_r(t))] dt}{\int_0^{t_f} \hat{\omega}(t)^T \cdot \hat{\omega}(t) dt} \leq \rho^2,$$

其中 $\hat{\omega}(t) = [\omega^T(t), r^T(t)]^T, Q = Q^T > 0$.

由(8)(4)(7)式得跟踪控制系统为

$$\begin{aligned} \dot{\bar{X}}(t) &= \sum_{k=1}^l \sum_{m=1}^l h_k(z(t)) h_m(z(t)) \{A_{km} \bar{X}(t) \\ &\quad + \Delta \hat{f} + D_k \bar{\omega}(t)\}. \end{aligned} \quad (9)$$

其中

$$\begin{aligned} \bar{X}(t) &= [X^T(t), X_r^T(t), e^T(t)]^T, \\ A_{km} &= \begin{bmatrix} A_k + B_k K_m & -B_k K_m & -B_k K_m \\ 0 & A_r & 0 \\ 0 & 0 & A_k - L_k C_m \end{bmatrix}, \\ D_k &= \begin{bmatrix} I & 0 & 0 \\ 0 & I & 0 \\ I & 0 & -L_k \end{bmatrix}, \end{aligned}$$

$$\bar{\omega}(t) = [\omega^T(t), r^T(t), v^T(t)]^T,$$

$$\Delta \hat{f} = [\Delta f^T \ 0 \ 0]^T.$$

若考虑初始条件, H_∞ 性能指标可重写为

$$\begin{aligned} \int_0^{t_f} \bar{X}^T(t) \bar{Q} \bar{X}(t) dt &\leq \rho^2 \int_0^{t_f} \bar{\omega}^T(t) \bar{\omega}(t) dt \\ &\quad + \bar{X}^T(0) \bar{P} \bar{X}(0). \end{aligned} \quad (10)$$

其中,

$$\bar{Q} = \begin{bmatrix} Q & -Q & 0 \\ -Q & Q & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$P = P^T > 0.$$

定理 1 对任何有界矩阵(或向量) X 和 Y 均满足

$$X^T Y + Y^T X \leq X^T J X + Y^T J^{-1} Y,$$

其中 J 为任意正定对称矩阵.

由定理 1 可得下列推论.

推论

$$\begin{aligned} \bar{X}^T(t) P \Delta \hat{f} + \Delta \hat{f}^T P \bar{X}(t) &\leq \Delta \hat{f}^T \Delta \hat{f} \\ + \bar{X}^T(t) P P \bar{X}(t) &\leq \sum_{i=1}^n \alpha_i \|X(t)\| \\ + \bar{X}^T(t) P P \bar{X}(t) &\leq \bar{X}^T(t) (\beta + \beta) \bar{X}(t), \end{aligned}$$

其中

$$\beta = \begin{bmatrix} (\sum_{i=1}^n \alpha_i) I & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}^{3N \times 3N}.$$

定理 2^[20] 对(9)式描述的系统, 如果存在 $P = P^T > 0$ 且满足不等式

$$\begin{bmatrix} A_{km}^T P + P A_{km} + \bar{Q} + P P + \beta & P D_k \\ D_k^T P & -\rho^2 I \end{bmatrix} \leq 0, \quad (11)$$

则系统在 $\bar{\omega}(t) \neq 0$ 时满足(10)式的 H_∞ 性能指标.

证

$$\begin{aligned} &\int_0^{t_f} [(X(t) - X_r(t))^T Q (X(t) - X_r(t))] dt \\ &= \int_0^{t_f} \bar{X}^T(t) \bar{Q} \bar{X}(t) dt \\ &= \bar{X}^T(0) \bar{P} \bar{X}(0) - \bar{X}^T(t_f) \bar{P} \bar{X}(t_f) + \int_0^{t_f} \{ \bar{X}^T(t) \bar{Q} \bar{X}(t) \\ &\quad + \frac{d}{dt} (\bar{X}^T(t) \bar{P} \bar{X}(t)) \} dt \leq \bar{X}^T(0) \bar{P} \bar{X}(0) \\ &\quad + \int_0^{t_f} \{ \bar{X}^T(t) \bar{Q} \bar{X}(t) + \dot{\bar{X}}^T(t) \bar{P} \bar{X}(t) \\ &\quad + \bar{X}^T(t) \dot{\bar{P}} \bar{X}(t) \} dt \\ &= \bar{X}^T(0) \bar{P} \bar{X}(0) + \int_0^{t_f} \{ \bar{X}^T(t) \bar{Q} \bar{X}(t) \\ &\quad + \left[\sum_{k=1}^l \sum_{m=1}^l h_k(z(t)) h_m(z(t)) \times (A_{km} \bar{X}(t) \right. \\ &\quad \left. + \Delta \hat{f} + D_k \bar{\omega}(t)) \right]^T \bar{P} \bar{X}(t) \end{aligned}$$

$$\begin{aligned}
& + \bar{X}^T(t)P \left[\sum_{k=1}^l \sum_{m=1}^l h_k(\mathcal{X}(t))h_m(\mathcal{X}(t)) \right. \\
& \times (A_{km}\bar{X}(t) + \Delta\hat{f} + D_k\bar{\omega}(t)) \left. \right] \\
& - \rho^2 \bar{\omega}^T(t)\bar{\omega}(t) + \rho^2 \bar{\omega}^T(t)\bar{\omega}(t) \Big\} dt \\
\leq & \bar{X}^T(0)P\bar{X}(0) + \sum_{k=1}^l \sum_{m=1}^l h_k(\mathcal{X}(t))h_m(\mathcal{X}(t)) \\
& \times \int_0^{t_f} \left\{ \begin{bmatrix} \bar{X}^T(t) \\ \bar{\omega}^T(t) \end{bmatrix}^T \right. \\
& \times \begin{bmatrix} A_{km}^T P + PA_{km} + \bar{Q} + PP + \beta & PD_k \\ D_k^T P & -\rho^2 I \end{bmatrix} \\
& \left. \times \begin{bmatrix} \bar{X}(t) \\ \bar{\omega}(t) \end{bmatrix} + \rho^2 \bar{\omega}^T(t)\bar{\omega}(t) \right\} dt,
\end{aligned}$$

若不等式 (11) 满足时 则 (10) 式成立.

定理 2 将 H_∞ 跟踪控制变成在 $\min_P \rho^2$ 下 寻求 $P = P^T > 0$ 来满足 (11) 式的 LMI 凸优化问题. 令

$$W = \begin{bmatrix} \bar{W} & 0 \\ 0 & I \end{bmatrix} = \begin{bmatrix} P^{-1} & 0 \\ 0 & I \end{bmatrix},$$

因 $P = P^T > 0$ 则

$$W = W^T > 0.$$

由 (11) 式可得

$$W \begin{bmatrix} A_{km}^T P + PA_{km} + \bar{Q} + PP + \beta & PD_k \\ D_k^T P & -\rho^2 I \end{bmatrix} W \leq 0,$$

即

$$\begin{bmatrix} \bar{W}A_{km}^T + A_{km}\bar{W} + \bar{W}Q\bar{W} + \bar{W}(PP + \beta)\bar{W} & D_k \\ D_k^T & -\rho^2 I \end{bmatrix} \leq 0.$$

$$\begin{bmatrix} \bar{W}A_{km}^T + A_{km}\bar{W} & \bar{W}Q^{1/2} & \bar{W}P & \bar{W}\beta^{1/2} & D_k \\ (\bar{Q}^{1/2})^T \bar{W} & -I & 0 & 0 & 0 \\ P\bar{W} & 0 & -I & 0 & 0 \\ (\beta^{1/2})^T \bar{W} & 0 & 0 & -I & 0 \\ D_k^T & 0 & 0 & 0 & -\rho^2 I \end{bmatrix} \leq 0,$$

为了设计方便 选取

$$P = \begin{bmatrix} P_{11} & 0 & 0 \\ 0 & P_{11} & 0 \\ 0 & 0 & P_{11} \end{bmatrix},$$

且 $P_{11} = P_{11}^T > 0$ 则

$$\bar{W} = \begin{bmatrix} W_{11} & 0 & 0 \\ 0 & W_{11} & 0 \\ 0 & 0 & W_{11} \end{bmatrix}$$

$$= \begin{bmatrix} P_{11}^{-1} & 0 & 0 \\ 0 & P_{11}^{-1} & 0 \\ 0 & 0 & P_{11}^{-1} \end{bmatrix},$$

并令 $Y_m = K_m W_{11}$ 采用凸优化 LMI 的 MATLAB 工具箱求出 Y_m 和 W_{11} [19] 进而可获得控制器参数 K_m .

4. 仿真研究

描述受迫非线性波传播即耦合 Duffing 振子时空混沌的一维偏微分方程为

$$\begin{aligned}
\frac{\partial^2 \phi}{\partial t^2} = & -\alpha \frac{\partial \phi}{\partial t} - \delta_1 \phi^3 + \delta_2 \phi + \delta \frac{\partial^2 \phi}{\partial \lambda^2} \\
& + \eta \sin(\beta t) + d(t),
\end{aligned}$$

其中 δ_1, δ_2 是空间的无限延展的扩散系数, α 是介质阻尼系数, $\phi = \phi(\lambda, t)$ 是介质的局部位置, δ 是与波动群速有关的物理量, η, β 是外力的增益和频率, $d(t)$ 是外界所加有界扰动. 令 $\eta \sin(\beta t) + d(t) = \hat{d}(t), \phi(\lambda, t) \rightarrow x_{i1}(t)$, 耦合子系统的个数 $n = 2$, $\partial^2 \phi / \partial \lambda^2 = x_{22} - x_{12}$. 将 Duffing 振子变成两个耦合的子系统

$$\dot{x}_{i1} = x_{i2}$$

$$\begin{aligned}
\dot{x}_{i2} = & -\alpha x_{i2} - \delta_1 x_{i1}^3 + \delta_2 x_{i1} + \delta(x_{22} - x_{12}) + \hat{d}(t), \\
y_i(t) = & x_{i1}(t) + v_i(t),
\end{aligned}$$

其中 $x_i = [x_{i1}, x_{i2}]^T \in R^2$ 为子系统的状态向量, $y_i(t)$ 为子系统的输出变量, δ 是各子系统间的耦合强度. 现取 $\alpha = 1, \delta_1 = 100, \delta_2 = 10, \eta = 1, \beta = 3.5$. 随耦合强度 $\delta (0 < \delta < 10)$ 的增强, 耦合 Duffing 振子表现出极为丰富的非线性特性即时空混沌特性. 现取 $\delta = 8$, 参考输入

$$r(t) = [7.5(8 + 2\cos 1.5\pi t), 12.5(12 + \cos 1.5\pi t)]^T,$$

设 $\Delta f_i \leq 0.3 \|X(t)\|$ 并选取 4 个特定点在 4 条模糊规则下实现耦合 Duffing 振子模糊模型, 则采用凸优化 LMI 的 MATLAB 工具箱求得

$$W_{11} = \begin{bmatrix} 64.2453 & -33.3766 & 45.5986 & 2.4912 \\ -9.3642 & 28.6005 & -5.8790 & 15.8232 \\ 9.6665 & -5.9230 & 36.6769 & -7.4387 \\ 12.4923 & 6.4646 & -10.6332 & 44.7903 \end{bmatrix}.$$

控制器参数

$$\begin{aligned}
K_1 = & \begin{bmatrix} 8.3366 & -68.8965 & -27.9836 & 4.2980 \\ 16.9052 & -7.1221 & -53.9234 & 43.7898 \end{bmatrix}, \\
K_2 = & \begin{bmatrix} 8.3455 & -69.1732 & -25.3567 & 5.9087 \\ 17.9964 & -7.7865 & -52.7823 & 44.4367 \end{bmatrix},
\end{aligned}$$

$$K_3 = \begin{bmatrix} 9.9763 & -68.9012 & -26.9342 & 4.1234 \\ 16.3425 & -6.5634 & -54.9719 & 42.8912 \end{bmatrix},$$

$$K_4 = \begin{bmatrix} 8.5674 & -66.4523 & -24.9701 & 4.8895 \\ 17.8969 & -5.9069 & -53.7895 & 43.0782 \end{bmatrix}.$$

初始点选为 $[7.5, 8.5, 12.5, 11.2]$,在 $t = 1.5 \text{ s}$ 施加控制,系统的跟踪性能如图1所示.仿真实验验证了方案跟踪性能的有效性.

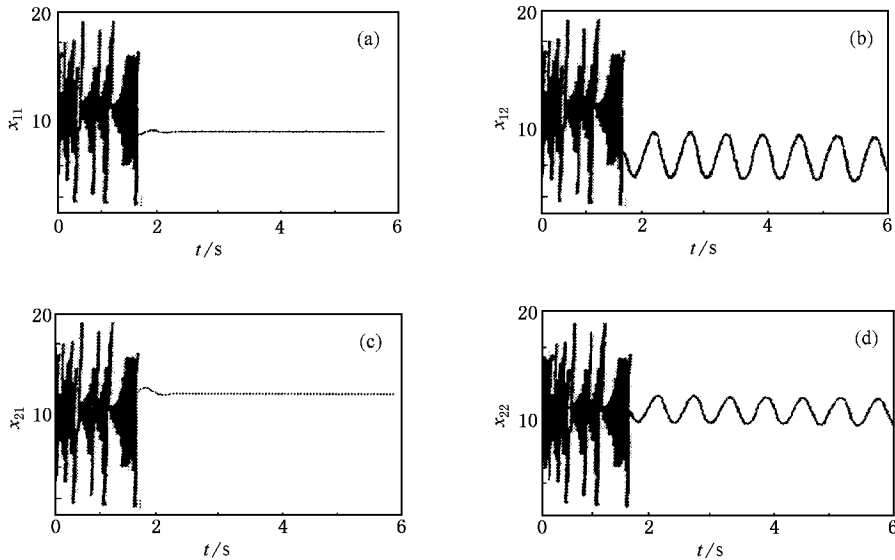


图1 耦合混沌系统状态跟踪曲线 (a) x_{11} 的状态跟踪轨迹, (b) x_{12} 的状态跟踪轨迹, (c) x_{21} 的状态跟踪轨迹, (d) x_{22} 的状态跟踪轨迹

5. 结 论

考虑耦合时空混沌模型的不确定性和子系统状态的不可测性,基于耦合子系统的一系列局部线性化 T-S 模糊模型和模糊状态观测器,提出一种 H_∞

模糊跟踪控制方案并应用到模型不确定的耦合时空混沌的跟踪控制中.将该控制表征为求解 LMI 问题,并采用凸优化方法求解控制器的参数.该方案能克服外界扰动,确保系统的全局渐近稳定性.仿真实验验证了方案跟踪性能的有效性.

- [1] Davison E J 1994 *Automatic* **10** 309
- [2] Zhang X, Shen K 2002 *Acta Phys. Sin.* **51** 2702 [in Chinese] 张旭、沈柯 2002 物理学报 **51** 2702
- [3] Chen B S, You W S 1987 *IEEE Tran. Automatic Contr.* **32** 1131
- [4] Ren H P, Liu D 2002 *Acta Phys. Sin.* **51** 982 [in Chinese] 任海鹏、刘丁 2002 物理学报 **51** 982
- [5] Chen B S, Tseng C S 1999 *IEEE Tran. Fuzzy Syst.* **7** 571
- [6] Yue D 2003 *Acta Phys. Sin.* **52** 292 [in Chinese] 岳东 2003 物理学报 **52** 292
- [7] Tseng C S, Chen B S 2001 *IEEE Tran. Fuzzy Syst.* **9** 381
- [8] Chen B S, Lee C H, Chang Y C 1996 *IEEE Trans. Fuzzy Syst.* **4** 32
- [9] Wu Z Q, Ao D, Liu K 2004 *Acta Phys. Sin.* **53** 21 [in Chinese] [吴志强、奥顿、刘坤 2004 物理学报 **53** 21]
- [10] Tseng C S, Chen B S 2001 *IEEE Tran. Fuzzy Syst.* **9** 795
- [11] Chen S H, Liu L M, Liu J 2002 *Chin. Phys.* **11** 543
- [12] Wu Z Q 2002 *Acta Phys. Sin.* **51** 1193 [in Chinese] [吴志强 2002 物理学报 **51** 1193]
- [13] Mu J, Tao C, Du G H 2003 *Chin. Phys.* **12** 381
- [14] Chen B S, Tseng C S, Uang H J 2000 *IEEE Tran. Fuzzy Syst.* **8** 249
- [15] Kim E, Lee H 2000 *IEEE Tran. Fuzzy Syst.* **8** 523
- [16] Siljak D D, Vukcevic M 1986 *IEEE Tran. Automatic Contr.* **31** 363
- [17] Kim E, Kim S 2001 *IEEE Tran. Fuzzy Syst.* **10** 391
- [18] Chan W S, Desoer C A 1980 *IEEE Tran. Automatic Contr.* **25** 106
- [19] Scherer C, Gahinet P 1997 *IEEE Tran. Automatic Contr.* **42** 896
- [20] Chen B S, Chen Y Y, Lin C L 2002 *IEEE Tran. Contr. Syst.* **10** 769

H_∞ tracking control for coupled spatio-temporal chaos with uncertain model based on fuzzy observers *

Dou Chun-Xia Zhang Shu-Qing

(College of Electrical Engineering , Yanshan University , Qinghuangdao 066004 , China)

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Abstract

Due to the interactions among coupled spatio-temporal subsystems and the model uncertainties , it is difficult to achieve tracking control for coupled spatio-temporal chaos with uncertain model. However , every subsystem of the coupled spatio-temporal chaos is approximated by a set of fuzzy models. Considering that the states of the subsystems are not all available , a set of fuzzy observers are proposed to estimate these states. Because it is very difficult to exactly eliminate many parameters and dynamic characters of the chaotic system , that is to say , the system model is uncertain , there can be deviation between the fuzzy models and the real chaotic system due to approximation error. Based on these fuzzy models and observers , considering the model uncertainties , a H_∞ fuzzy tracking control scheme is proposed , and the robust tracking control for the coupled spatio-temporal chaos with the uncertain model is achieved by the above scheme. A linear matrix inequality is employed to represent the feedback controller , the parameters of the controller being obtained by using the convex optimization techniques of linear matrix inequalities. The stability of the system is guaranteed and the tracking performances are tested by a simulation example.

Keywords : coupled spatio-temporal chaos , fuzzy models , fuzzy observers , H_∞ fuzzy tracking control , linear matrix inequalities

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