

具有混合时滞的随机神经网络的无源性分析

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摘 要: 针对一类具有混合时滞的随机神经网络, 研究其无源性分析问题. 假设神经网络的离散状态时滞是不确定的, 看成一个标称值受时变扰动; 神经网络的分布式状态时滞是定常的. 通过构造适当的离散化 Lyapunov-Krasovskii 泛函, 并结合自由权矩阵方法, 以线性矩阵不等式的形式给出了保证具有混合时滞的随机神经网络无源的时滞依赖充分条件.

关键词: 无源性; 随机神经网络; 混合时滞

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Passivity Analysis for Stochastic Neural networks With Mixed Delays

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Abstract: This paper is concerned with the problem of passivity analysis for stochastic neural networks with mixed delays. It is assumed that the discrete delay is uncertain and seen as a composition of a nominal value subject to a time varying perturbation. The distributed delay is supposed to be constant. By constructing a appropriate discretized Lyapunov-Krasovskii functional and utilizing free-weight matrix techniques, delay-dependent passivity criteria are established in terms of linear matrix inequalities to guarantee the passivity performance of the addressed neural networks.

Key words: passivity; stochastic neural networks; mixed delays

1 引言

时滞神经网络的动态特性与综合分析研究已受到广泛的关注^[1]. 无源性理论是研究非线性系统稳定性的有效工具, 在复杂性、信号处理、模糊控制等领域均有应用. 文献[2-6]研究了时滞神经网络的无源性分析问题. 考虑到实际神经网络不可避免地会受到随机干扰, 本文将研究一类具有混合时滞的连续时间随机神经网络的无源性分析问题. 假设神经网络的离散状态时滞是不确定的, 看成一个标称值受时变扰动; 神经网络的分布式状态时滞是定常的. 为了获得保守性较小的时滞依赖无源性条件, 本文利用离散化 Lyapunov-Krasovskii 泛函思想^[7], 提出了新的 Lyapunov-Krasovskii 泛函.

2 问题描述

记号: 文中, R^n 表示 n 维实向量空间; $R^{n \times n}$ 表示 $n \times n$ 维实矩阵的集合; I 表示适当维数的单位向量; $P > 0$ (< 0 , ≤ 0 , ≥ 0) 表示对称矩阵 P 为正定(负定, 半负定, 半正定); 符号“ T ”表示矩阵的转置; 符号“ $*$ ”表示矩阵对阵位置元素的转置; $\text{diag}\{\cdots\}$ 表示对角矩阵; $E\{\cdot\}$ 表示数学期望; 定义 $\text{sym}\{A\} = A^T + A$

考虑如下具有混合时滞的随机神经网络:

$$\begin{aligned} dx(t) = & [-Cx(t) + Af(x(t)) + \\ & Bf(x(t-d(t))) + D \int_{-\tau}^t h(x(s))ds + \\ & u(t)]dt + \sigma(t, x(t), x(t-d(t)))d\omega(t), \end{aligned}$$

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$$z(t) = f(x(t)) \quad (1)$$

式中, $x(t) = [x_1(t), x_2(t), \dots, x_n(t)]^T$ 是网络的 n 维状态向量, $u(t) \in R^m$ 是网络的外部输入向量, $z(t)$ 是输出向量, $\omega(t)$ 是一维布朗运动. $C = \text{diag}\{c_1, c_2, \dots, c_n\}$ 为一正定对角矩阵, A, B 和 D 分别为与时滞无关的连接权矩阵, 与状态时滞相关的连接权矩阵和与状态分布的时滞相关的连接权矩阵, 不确定时滞 $d(t)$ 为 $d(t) = d + \delta(t)$, 其中 d 为常数, $\delta(t)$ 为时变扰动且满足 $|\delta(t)| \leq \delta < d$, 且 $d(t) \in [d - \delta, d + \delta]$. $\tau > 0$ 为常值分布式时滞. 神经元激励函数 $f(x(t)) = [f_1(x_1), f_2(x_2), \dots, f_n(x_n)]^T$ 分别满足 $f(0) = 0$ 和 $h(0) = 0$, 且满足如下假设:

假设 1: 对 $i = 1, 2, \dots, n$, 存在常量 F_i^-, F_i^+, H_i^- 和 H_i^+ 使得

$$F_i^- \leq \frac{f_i(s_1) - f_i(s_2)}{s_1 - s_2} \leq F_i^+, \forall s_1 \neq s_2 \in \mathbf{R} \quad (2)$$

$$H_i^- \leq \frac{h_i(s_1) - h_i(s_2)}{s_1 - s_2} \leq H_i^+, \forall s_1 \neq s_2 \in \mathbf{R} \quad (3)$$

噪声强度函数 $\sigma(t, x, y)$ 满足 $\sigma(t, 0, 0) = 0$, 并且有

$$\text{trace}(\sigma^T(t, x, y)) \leq \|G_1 x\|^2 + \|G_2 y\| \quad (4)$$

式中, G_1 和 G_2 是已知的常数矩阵.

给出系统(1)的初始条件为

$$x(s) = \varphi(s), s \in [-\bar{d}, 0], \bar{d} = \max\{d + \delta, \tau\}$$

式中, φ 为连续函数且满足 $\sup_{s \leq 0} \mathbf{E}\{\|\varphi(s)\|^2\} < \infty$, 相应的状态轨迹记为 $x(t; \varphi)$.

定义 1 若存在常数 $\gamma > 0$ 使得在零初始条件下, 对所有的 $t_p > 0$, 有

$$2E\{\int_0^{t_p} z^T(s)u(s)ds\} \leq -E\{\gamma \int_0^{t_p} u z^T(s)u(s)ds\} \quad (5)$$

则称网络(1)是无源的.

引理 1 $G \in \mathbf{R}^{l \times l}$ 为对称正定矩阵, $r > 0$ 为正实数, 则对任意的常数矩阵 $M \in \mathbf{R}^{n \times l}$, 满足如下不等式:

$$2u^T M v \leq r u^T M G M^T u + \frac{1}{r} v^T G^{-1} v, u \in \mathbf{R}^n, v \in \mathbf{R}^l$$

3 主要结果

下面的定理给出了神经网络(1)与时滞相关的无源性条件.

定理 1 对于给定的正整数 N , 若存在矩阵 $P_1 > 0, S > 0, W_1 > 0, W_2 > 0, Z_i > 0, Q_i > 0, R_{ij} = R_{ji}^T (i, j = 0, 1, \dots, N), P_2, P_3, M_k (k = 1, 2, 3, 4)$, 正定对角矩阵 L, Λ 以及常数 $\rho_1 > 0, \rho_2 > 0, \gamma > 0$, 使得如下线性矩阵不等式组成立:

$$P_1 < \rho_1 I \quad (6)$$

$$S < \rho_2 I \quad (7)$$

$$\begin{bmatrix} \Omega + \Phi + \Phi^T & D^s & D^a & \delta M & \delta M \\ * & -R_d - Z_d & 0 & 0 & 0 \\ * & * & -3Z_d & 0 & 0 \\ * & * & * & -\delta W_1 & 0 \\ * & * & * & * & -\delta S \end{bmatrix} < 0 \quad (8)$$

$$\begin{bmatrix} P_1 & \bar{Q} \\ * & \bar{R} + \bar{Z} \end{bmatrix} > 0 \quad (9)$$

其中 $\bar{Q} = [Q_0 \ Q_1 \ \dots \ Q_N]$,

$$\bar{Z} = \text{diag}\left\{\frac{1}{h}Z_0, \frac{1}{h}Z_1, \dots, \frac{1}{h}Z_N\right\}, h = d/N,$$

$\bar{R} = [R_{ij}]$, R_{ij} 为矩阵 $\bar{R}$ 中 (i, j) 位置的元素.

$$\Omega = \begin{bmatrix} \Omega_{11} & \Omega_{12} & -Q_N & 0 & P_2 A + F_2 L & P_2 B & H_2 \Lambda & P_2 D & P_2 \\ * & \Omega_{22} & 0 & 0 & P_3 A & P_3 B & 0 & P_3 D & P_3 \\ * & * & -Z_N & 0 & 0 & 0 & 0 & 0 & 0 \\ * & * & * & \Omega_{44} & 0 & F_2 U & 0 & 0 & 0 \\ * & * & * & * & -L & 0 & 0 & 0 & -I \\ * & * & * & * & * & -U & 0 & 0 & 0 \\ * & * & * & * & * & * & -\tau^2 W_2 - \Lambda & 0 & 0 \\ * & * & * & * & * & * & * & -W_2 & 0 \\ * & * & * & * & * & * & * & * & -\gamma I \end{bmatrix}$$

$$\Omega_{11} = \text{sym}\{Q_0 - P_2 C\} + Z_0 + \bar{\rho} G_1^T G_1 - F_1 L - H_1 \Lambda,$$

$$\Omega_{12} = P_1 - P_2 - C P_3,$$

$$\bar{\rho} = \rho_1 + 2\delta\rho_2,$$

$$F_1 = \text{diag}\{F_1^- F_1^+, F_2^- F_2^+, \dots, F_n^- F_n^+\},$$

$$F_2 = \text{diag}\left\{\frac{F_1^- + F_1^+}{2}, \frac{F_2^- + F_2^+}{2}, \dots, \frac{F_n^- + F_n^+}{2}\right\},$$

$$H_1 = \text{diag}\{H_1^- H_1^+, H_2^- H_2^+, \dots, H_n^- H_n^+\},$$

$$H_2 = \text{diag}\left\{\frac{H_1^- + H_1^+}{2}, \frac{H_2^- + H_2^+}{2}, \dots, \frac{H_n^- + H_n^+}{2}\right\},$$

$$\Omega_{22} = 2\delta W_1 - P_3 = P_3^T, \Omega_{44} = \bar{\rho} G_2^T G_2 - F_1 U,$$

$$\Phi = [0 \ 0 \ M \ -M \ 0 \ 0 \ 0 \ 0 \ 0],$$

$$M = [M_1^T \ M_2^T \ M_3^T \ M_4^T \ 0 \ 0 \ 0 \ 0 \ 0]^T$$

$$D^i = [D_1^i \ D_2^i \ \dots \ D_N^i],$$

$$D^a = [D_1^a \ D_2^a \ \dots \ D_N^a],$$

$$D_i^i = \begin{bmatrix} \frac{h}{2}(R_{0,i-1} + R_{0,i}) - (Q_{i-1} - Q_i) \\ \frac{h}{2}(Q_{i-1} + Q_i) \\ -\frac{h}{2}(R_{i-1,N}^T + R_{i,N}^T) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix},$$

$$D_i^a = \begin{bmatrix} -\frac{h}{2}(R_{0,i-1} - R_{0,i}) \\ -\frac{h}{2}(Q_{i-1} - Q_i) \\ \frac{h}{2}(R_{i-1,N}^T - R_{i,N}^T) \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix},$$

$$Z_d = -\text{diag}\{Z_0 - Z_1, Z_1 - Z_2, \dots, Z_{N-1} - Z_N\}.$$

$$R_d = [R_{dij}] \text{ 且 } R_{dij} = \frac{1}{h}[R_{i-1,j-1} - R_{i,j}]$$

则网络(1)是无源的。

证明: 为简便起见, 记 $y(t) = -Cx(t) + Af(x(t)) + Bf(x(t-d(t))) + D \int_{t-\tau}^t h(x(s))ds = u(t)$, $\alpha(t) = \sigma(t, x(t), x(t-d(t)))$, 则网络(1)可由下式表示:

$$dx(t) = y(t)dt + \alpha(t)d\omega(t) \quad (10)$$

定义 Lyapunov-Krasovskii 泛函如下:

$$V(t) = V_d(t) + V_\delta(t) + V_\tau(t) \quad (11)$$

其中

$$V_d(t) = x^T(t)P_1x(t) + 2x^T(t) \int_{-d}^0 Q(s)x(t+s)ds + \int_{-d}^0 \int_{-d}^0 x^T(t+s)R(s,\theta)dx(t+\theta)d\theta + \int_{-d}^0 x^T(t+s)Z(s)x(t+s)ds,$$

$$V_\delta(t) = \int_{-\delta}^\delta \int_{t+\theta-d}^t y^T(s)W_1y(s)dsd\theta + \int_{-\delta}^\delta \int_{t+\theta-d}^0 \alpha^T(s)S_\alpha(s)dsd\theta,$$

$$V_\tau(t) = \tau \int_0^\tau \int_{t-s}^t h^T(x(\theta))W_2h(x(\theta))d\theta ds$$

由 Ito 公式可得

$$dV(t) = \mathcal{N}(t)dt + \left[2x^T(t)P_1 + 2\left(\int_{-d}^0 Q(s)x(t+s)dx\right)^T \right] \alpha(t)d\omega(t) \quad (12)$$

其中

$$\mathcal{N}(t) = \mathcal{N}_d(t) + \mathcal{N}_\delta(t) + \mathcal{N}_\tau(t),$$

$$\begin{aligned} \mathcal{N}_d(t) = & 2x^T(t)P_1y(t) + \alpha^T(t)P_1\alpha(t) + \\ & 2y^T(t) \int_{-d}^0 Q(s)x(t+s)ds + 2x^T(t)[Q(0)x(t) - \\ & Q(-d)x(t-d) - \int_{-d}^0 \dot{Q}(s)x(t+s)ds] + \\ & x^T(t)Z(0)x(t) - x^T(t-d)Z(-d)x(t-d) - \\ & \int_{-d}^0 x^T(t+s)\dot{Z}(s)x(t+s)ds + 2 \int_{-d}^0 x^T(t)R(0,s)x(t \\ & + s)ds - 2 \int_{-d}^0 x^T(t-d)R(-d,s)s(t+s)ds - \\ & \int_{-d}^0 \int_{-d}^0 x^T(t+s) \left[\frac{\partial R(s,\theta)}{\partial s} + \frac{\partial R(s,\theta)}{\partial \theta} \right] x(t+\theta)d\theta ds, \end{aligned}$$

$$\mathcal{N}_\delta(t) = 2\delta y^T(t)W_1y(t) + 2\delta \alpha^T(t)S_\alpha(t) - \int_{-d-\delta}^{t-d+\delta} y^T(s)W_1y(s)ds - \int_{-d-\delta}^{t-d+\delta} \alpha^T(s)S_\alpha(s)ds,$$

$$\mathcal{N}_\tau(t) = \tau^2 h^T(x(t))W_2h(x(t)) -$$

$$\tau \int_{t-\tau}^t h^T(x(s))W_2h(x(s))ds$$

$$\leq \tau^2 h^T(x(t))W_2h(x(t)) -$$

$$\int_{t-\tau}^t h^T(x(s))ds W_2 \int_{t-\tau}^t h^T(x(s))ds.$$

又由式(10)可知, 对于任意的恰当维数的矩阵 $M_i, i=1, 2, 3, 4$, 下式成立:

$$0 = 3\xi^T(t)M[x(t-d) - x(t-d(t)) - \int_{t-d(t)}^{t-d} y(s)ds - \int_{t-d(t)}^{t-d} \alpha(s)d\omega(s)] = \psi_1 \quad (13)$$

其中, $M = [M_1^T \ M_2^T \ M_3^T \ M_4^T \ 0 \ 0 \ 0 \ 0 \ 0]^T$.

$$\xi(t) = [x^T(t) \ y^T(t) \ x^T(t-d) \ x^T(t-d(t)) \ f^T(x(t)) \ f^T(x(t-d(t))) \ h^T(x(t)) \ \int_{t-d}^t h^T(x(s))ds \ u^T(t)]^T$$

则由引理1可知

$$\begin{aligned} -2\xi^T(t)M \int_{t-d(t)}^{t-d} y(s)ds &\leq (d(t)-d) \\ \xi^T(t)MW_1^{-1}M^T\xi(t) + \int_{t-d(t)}^{t-d} y^T(s)W_1y(s)ds &\leq \\ \delta\xi^T(t)MW_1^{-1}M^T\xi(t) + \int_{t-d-\delta}^{t-d+\delta} y^T(s)ds \\ \mathbf{E}\{-2\xi^T(t)M \int_{t-d(t)}^{t-d} \alpha(s)d\omega(s)\} &\leq \\ \mathbf{E}\{\delta\xi^T(t)MS^{-1}M^T\xi(t) + \\ \mathbf{E}\int_{t-d-\delta}^{t-d+\delta} \alpha^T(s)S\alpha(s)ds\} \end{aligned}$$

由 $y(t)$ 的定义有

$$\begin{aligned} 0 = 2[x^T(t)P_2 + y^T(t)P_3][&-y(t) - Cx(t) + \\ Af(t)] + Bf(x(t-d(t))) + D \int_{t-d}^t h(x(s))ds + \\ u(t) &= \Psi_2 \end{aligned} \quad (14)$$

式中, P_2, P_3 为适当维数的矩阵.

由假设1可知, 对任意的对角矩阵 $L > 0, U > 0$ 和 $\Lambda > 0$, 有

$$\Psi_3 = \begin{bmatrix} x(t) \\ f(x(t)) \end{bmatrix}^T \begin{bmatrix} F_1L & -F_2L \\ -F_2L & L \end{bmatrix} \begin{bmatrix} x(t) \\ f(x(t)) \end{bmatrix} \leq 0 \quad (15)$$

$$\begin{aligned} \Psi_4 = \begin{bmatrix} x(t-d(t)) \\ f(x(t-d(t))) \end{bmatrix}^T \begin{bmatrix} F_1U & -F_2U \\ -F_2U & U \end{bmatrix} \\ \begin{bmatrix} x(t-d(t)) \\ f(x(t-d(t))) \end{bmatrix} \leq 0 \end{aligned} \quad (16)$$

$$\Psi_5 = \begin{bmatrix} x(t) \\ h(x(t)) \end{bmatrix}^T \begin{bmatrix} H_1\Lambda & -H_2\Lambda \\ -H_2\Lambda & \Lambda \end{bmatrix} \begin{bmatrix} x(t) \\ h(x(t)) \end{bmatrix} \leq 0 \quad (17)$$

因此

$$\begin{aligned} \mathbf{E}\{\mathcal{V}(t) - 2z^T(t)u(t) - \gamma u^T(t)u(t)\} &\leq \\ \mathbf{E}\{\mathcal{V}(t) - 2z^T(t)u(t) - \gamma u^T(t)u(t) + \phi_1 + \phi_2 - \phi_3 \\ - \phi_4 - \phi_5\} &\leq \mathbf{E}\{\xi^T(t)\Psi\xi(t) + 2y^T(t) \int_{t-d}^0 Q(s)x(t+s)ds - 2 \int_{t-d}^0 \dot{Q}(s)x(t+s)ds + 2 \int_{t-d}^0 x^T(t)R(0,s)x(t+s)ds - 2 \int_{t-d}^0 x^T(t-d)R(-d,s)x(t+s)ds - \int_{t-d}^0 x^T(t+s) \end{aligned}$$

$$s)\dot{Z}(s)x(t+s)ds - \int_{-d}^0 \int_{-d}^0 x^T(t+s) \left[\frac{\partial R(s,\theta)}{\partial s} + \frac{\partial R(s,\theta)}{\partial \theta} \right] x(t+\theta)d\theta ds \}$$

其中, $\Psi = \Omega + \Phi + \Phi^T + \delta MW_1^{-1}M^T + \delta MS^{-1}M^T$

运用离散化泛函方法^[7], 将时滞区间 $[-d, 0]$ 划分为等长的 N 个小区间 $[\theta_i, \theta_{i-1}]$, $i=1, 2, \dots, N$, 步长为 $h = \frac{d}{N}$, $\theta_i = -ih$. 利用同样的方法将区域 $[-d, 0] \times [-d, 0]$ 划分为 $N \times N$ 个小区 $[\theta_i, \theta_{i-1}] \times [\theta_j, \theta_{j-1}]$. 选取连续矩阵函数 $Q(s)$, $Z(s)$ 与 $R(s, \theta)$, 其中 $Q(s)$, $Z(s)$ 在每个小区间上均为线性的, $R(s, \theta)$ 在每个三角区域内均为线性的. 使用线性插值公式将 $Q(s)$, $Z(s)$ 与 $R(s, \theta)$ 表示为如下形式:

$$Q(\theta_i + \alpha h) = (1-\alpha)Q_i + \alpha Q_{i-1},$$

$$Z(\theta_i + \alpha h) = (1-\alpha)Z_i + \alpha Z_{i-1},$$

$$R(\theta_i + \alpha h, \theta_j + \beta h) =$$

$$\begin{cases} (1-\alpha)R_{i,j} + \beta R_{i-1,j-1} + (\alpha-\beta)R_{i-1,j}, & \alpha \geq \beta \\ (1-\beta)R_{i,j} + \alpha R_{i-1,j-1} + (\beta-\alpha)R_{i-1,j}, & \alpha < \beta \end{cases}$$

其中, $i, j=0, 1, \dots, N, \alpha, \beta \in [0, 1]$. 记

$$\dot{Z}(s) = \frac{1}{h}(Z_{i-1} - Z_i)$$

$$\dot{Q}(s) = \frac{1}{h}(Q_{i-1} - Q_i)$$

$$\frac{\partial R(s,\theta)}{\partial s} + \frac{\partial R(s,\theta)}{\partial \theta} = \frac{1}{h}(R_{i-1,j-1} - R_{i,j})$$

通过计算可得

$$\begin{aligned} \mathbf{E}\{\mathcal{V}(t) - 2z^T(t)u(t) - \gamma u^T(t)u(t)\} &\leq \\ \mathbf{E}\{\xi^T(t)\Psi\xi(t) - \int_0^1 \phi^T(t,\alpha)Z_\alpha\phi(t,\alpha)d\alpha - \int_0^1 \int_0^1 \phi^T(t, \\ \alpha)R_\alpha\phi(t,\beta)d\alpha d\beta + 2\xi^T(t) \int_0^1 [D^x + (1-2\alpha)D^x] \phi(t, \\ \alpha)d\alpha\} \end{aligned} \quad (18)$$

其中

$$\phi(t, \alpha) = [x^T(t-h+\alpha h) \ x^T(t-2h+\alpha h) \ \dots \ x^T(t-Nh+\alpha h)]^T$$

对任意矩阵 $T > 0$ 且

$$\begin{bmatrix} T & -I \\ -I & Z_d \end{bmatrix} > 0$$

则利用 Jensen 不等式, 由式(18)可得

$$\begin{aligned} \mathbf{E}\{\mathcal{V}(t) - 2z^T(t)u(t) - \gamma u^T(t)u(t)\} &\leq \\ \mathbf{E}\{\xi^T(t)\Psi\xi(t) - \int_0^1 \eta^T(t,\alpha)d\alpha \begin{bmatrix} T & -I \\ -I & Z_d \end{bmatrix} \int_0^1 \eta(t,\alpha)d\alpha + \end{aligned}$$

$$\int_0^1 \xi^T(t, \alpha) T \xi(t, \alpha) d\alpha - \int_0^1 \phi^T(t, \alpha) d\alpha R_d \int_0^1 \phi(t, \alpha) d\alpha \}$$

其中

$$S^T(t, \alpha) = \xi^T(t) [D^s + (1-2\alpha)D^a],$$

$$\eta^T(t, \alpha) = [S^T(t, \alpha), \phi^T(t, \alpha)].$$

经计算可得

$$E\{\mathcal{N}(t) - 2z^T(t)u(t) - \gamma u^T(t)u(t)\} \leq S^T(t)$$

$$\Psi_1 S(t) \quad (19)$$

其中

$$S(t) = [\xi^T(t) \int_0^1 \phi^T(t, \alpha) d\alpha]^T$$

且

$$\Psi_1 = \begin{bmatrix} \Psi + 1/3 D^s T (D^a)^T & D^s \\ (D^s)^T & -R_d - Z_d \end{bmatrix}$$

由 Schur 补引理可知, 式(8)等价于 $\Psi_1 < 0$. 由 $dV(t)$ 的定义可知

$$E\{dV(t) - 2z^T(t)u(t)dt - \gamma u^T(t)u(t)dt\} \leq 0 \quad (20)$$

若 $Z_k > 0, k = 0, 1, \dots, N$, 且式(9)成立, 则 Lyapunov 泛涵 $V(t)$ 满足 $V(t) \geq \lambda \|x(t)\|^2, \lambda > 0$ [7] ([14], P. 185).

对于任意的 $t_p > 0$, 将式(20)的两边关于 t 从 0 到 t_p 积分, 则在零初始条件下, 有

$$2E\left\{\int_0^{t_p} z^T(s)u(s)ds\right\} \geq -\gamma E\left\{\int_0^{t_p} u^T(s)u(s)ds\right\} \quad (21)$$

由定义 1 知, 随机神经网络(1)是无源的

4 结束语

本文研究了一类具有离散时滞和分布式时滞的随机神经网络的无源性分析问题. 基于离散化 Lyapunov-Krasovskii 泛涵方法和随机系统的无源性理论, 得到了神经网络的时滞依赖无源性条件. 利用

本文方法可进一步研究更为一般的具有混合时滞的随机神经网络,

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