REFERENCES

[1] L. Almeida, "A learning rule for asynchronous perceptrons with feedback in a combinatorial environment," in *Proc. First Int. Conf. Neural Networks*, 1987, pp. 609–618.

[2] K. Narendra and K. Parthasarathy, "Gradient methods for the optimization of dynamical systems containing neural networks," *IEEE Trans. Neural Networks*, vol. 2, pp. 252–262, 1991.

[3] B. Pearlmutter, "Learning state space trajectories in recurrent neural networks," *Neural Comput.*, vol. 1, pp. 263–269, 1989.

[4] F. Pineda, "Generalization of back-propagation to recurrent neural networks," *Phys. Rev. Lett.*, vol. 59, pp. 2229–2232, 1987.

[5] E. Sontag, *Mathematical Control Theory*. New York: Springer-Verlag, 1990.

[6] P. Werbos, "Backpropagation through time: What it does and how to do it," *Proc. IEEE*, vol. 78, pp. 1550–1560, 1990,

[7] R. Williams and D. Zipser, "A learning algorithm for continually running fully recurrent neural networks," *Neural Computat.*, vol. 1, pp. 270–280, 1989.

Nonlinear H_∞ Synchronization of Lur'e Systems: Dynamic Output Feedback Case

Johan A. K. Suykens, Paul F. Curran, Tao Yang, Joos Vandewalle, and Leon O. Chua

***Abstract*—In this letter we introduce a new master–slave synchronization scheme for Lur'e systems, which makes use of vector field modulation and dynamic output feedback in order to recover a message signal. The synchronization scheme is represented in standard plant form according to modern control theory. I/O properties of the scheme are analyzed using a dissipativity approach with a quadratic storage function and a supply rate with finite L_2-gain. The method avoids transmission of the full state vector. The controller design is based on a matrix inequality, corresponding to nonlinear H_∞ synchronization. The new scheme is illustrated on Chua's circuit.**

***Index Terms*—Chua's circuit, dissipativity, dynamic output feedback, L_2-gain, Lur'e systems, master–slave synchronization, matrix inequality, nonlinear H_∞ control.**

I. INTRODUCTION

With respect to secure communication using chaotic systems [5], [17], a new method for master–slave synchronization of Lur'e systems has recently been proposed in [13] for recovery of the message signal. The problem has been approached from the viewpoint of control theory, by representing the synchronization scheme in standard plant form. I/O properties are analyzed using a dissipativity approach with a quadratic storage function and a supply rate with finite L_2-gain. A full static state feedback controller is designed based on a matrix inequality, which corresponds to nonlinear H_∞ synchronization. Robustness against noise can be taken into account in the design. However the scheme requires the transmission of a number of signals equal to the number of state variables of the Lur'e system.

The aim of this letter is to present a new method for synchronizing the systems when fewer signals than the number of state variables are transmitted, which is an advantage with respect to implementation, particularly when the transmitted signals are voltages. Therefore we will apply a linear *dynamic output feedback* controller instead of a full static state feedback controller. This idea has been introduced in [14] and successfully applied to synchronization of chaotic and hyperchaotic Lur'e systems. While the scheme in [14] corresponds to the autonomous case, in this paper a message signal is introduced as external reference input.

This letter is organized as follows. In Section II we introduce the new synchronization scheme. In Section III we represent the scheme in standard plant form. In Section IV we derive a matrix inequality for dissipativity with finite L_2-gain and a quadratic storage function and formulate the corresponding nonlinear H_∞ synchronization problem. In Section V we illustrate the method on Chua's circuit. For additional motivations on the nonlinear H_∞ synchronization scheme we refer to [13].

II. SYNCHRONIZATION SCHEME

Consider the following master–slave synchronization scheme

$$
\begin{aligned}
\mathcal{R} &: \begin{cases} \dot{\mu} = R\mu + Sr \\ d = T\mu + Ur \end{cases} \\
\mathcal{M} &: \begin{cases} \dot{x} = Ax + B\sigma(Cx) + Dd \\ p = Hx \end{cases} \\
\mathcal{S} &: \begin{cases} \dot{z} = Az + B\sigma(Cz) + Fu \\ q = Hz \end{cases} \\
\mathcal{C} &: \begin{cases} \dot{\rho} = E\rho + G(p + \epsilon - q) \\ u = M\rho + N(p + \epsilon - q) \end{cases}
\end{aligned}
\tag{1}
$$

with master system $\mathcal{M}$, slave system $\mathcal{S}$, linear filter $\mathcal{R}$ and linear dynamic output feedback controller $\mathcal{C}$. The subsystems have state vectors $x, z \in R^n$, $\mu \in R^{n_r}$, $\rho \in R^{n_c}$ and output vectors $p, q \in R^l$, $u \in R^m$, $d \in R$, where $l, m \leq n$. The message signal is $r \in R$ and $\epsilon \in R^l$ is a disturbance input. At the transmitter $\mathcal{M}$, a linear transformation $H \in R^{l \times n}$ is applied to the state x. The resulting vector p is transmitted along the channel. At the receiver $\mathcal{S}$, linear dynamic output feedback is applied by taking the difference between p and q as input to the controller with system matrices $E \in R^{n_c \times n_c}$, $G \in R^{n_c \times l}$, $M \in R^{m \times n_c}$, $N \in R^{m \times l}$. The transmitted signal p is corrupted by the signal ϵ. The identical master–slave Lur'e systems have system matrices $A \in R^{n \times n}$, $B \in R^{n \times n_h}$ and $C \in R^{n_h \times n}$ where n_h corresponds to the number of hidden units (if one interprets the Lur'e system [8] as a class of recurrent neural networks [12]). The diagonal nonlinearity $\sigma(\cdot) : R^{n_h} \mapsto R^{n_h}$ is assumed to belong to sector $[0, k]$ (typically a linear characteristic with saturation or $\tanh(\cdot)$). At the master system the vector field is modulated by means of the term Dd. One has to ensure that the norm of this term is "small" compared to the norm of the other terms in the system dynamics. The low pass filter $\mathcal{R}$ has system matrices $R \in R^{n_r \times n_r}$, $S \in R^{n_r \times 1}$, $T \in R^{1 \times n_r}$, $U \in R$.

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$$\begin{cases} \begin{bmatrix} \dot{e} \\ \dot{\rho} \\ \dot{\mu} \end{bmatrix} = \begin{bmatrix} A - FNH & -FM & DT \\ GH & E & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} e \\ \rho \\ \mu \end{bmatrix} + \begin{bmatrix} B \\ 0 \\ 0 \end{bmatrix} \eta(Ce; z) + \begin{bmatrix} DU & -FN \\ 0 & G \\ S & 0 \end{bmatrix} \begin{bmatrix} r \\ \epsilon \end{bmatrix} \\ \nu = [-\beta^T \quad 0 \quad T] \begin{bmatrix} e \\ \rho \\ \mu \end{bmatrix} + [U \quad 0] \begin{bmatrix} r \\ \epsilon \end{bmatrix}. \end{cases} \tag{2}$$

III. Standard Plant Representation

According to [13], by defining the signal $e = x - z$ and the tracking error $\nu = d - \beta^T e$, where $\beta = [1; 0; 0; \cdots; 0]$ selects the first component of e, one obtains the following standard plant representation for the synchronization scheme: (see (2) at the top of the next page). This scheme has state vector $\xi = [e; \rho; \mu]$, exogenous input $w = [r; \epsilon]$ and regulated output ν. The nonlinearity η is given by $\eta(Ce; z) = \sigma(Ce + Cz) - \sigma(Cz)$.

IV. Dissipativity with Finite L_2-Gain and Nonlinear H_∞ Synchronization

In order to analyze I/O properties of the synchronization scheme in standard plant form (2), we consider a quadratic storage function [6], [7], [16]

$$\phi(\xi) = \xi^T P \xi = [e^T \quad \rho^T \quad \mu^T] \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix} \begin{bmatrix} e \\ \rho \\ \mu \end{bmatrix} \qquad P = P^T > 0 \tag{3}$$

and a supply rate with finite L_2-gain $s(r, \epsilon, \nu) = \gamma^2 \, (r^T r + \alpha^2 \epsilon^T \epsilon) - \nu^T \nu$, where α is a positive real constant. The system (2) is said to be dissipative [6], [7], [16] with respect to supply rate and the storage function if $\dot{\phi} \leq s(r, \epsilon, \nu)$, $\forall r, \epsilon, \nu$. Assume that the nonlinearity $\eta(Ce; z)$ belongs to sector $[0, k]$ [3]: $0 \leq \frac{\eta_i(c_i^T e; z)}{c_i^T e} = \frac{\sigma_i(c_i^T e + c_i^T z) - \sigma(c_i^T z)}{c_i^T e} \leq k, \forall e, z;\ (i = 1, \cdots, n_h;\ c_i^T e \neq 0)$. The inequality $\eta_i(c_i^T e; z)\, [\eta_i(c_i^T e; z) - k c_i^T e] \leq 0, \forall e, z; (i = 1, \cdots, n_h)$ holds then [8]. It follows from the mean value theorem that for differentiable $\sigma(\cdot)$ the sector $[0, k]$ condition on $\eta(\cdot)$ corresponds to $0 \leq \frac{d}{d\varphi} \sigma_i(\varphi) \leq k, \ \forall \varphi \, (i = 1, \cdots, n_h)$ [3].

Observation: Let $\Lambda = \mathrm{diag}\{\lambda_i\}$ be a diagonal matrix with $\lambda_i \geq 0$ for $i = 1, \cdots, n_h$. Then a sufficient condition for dissipativity of the synchronization scheme (2) with respect to the quadratic storage function (3) and the supply rate $s(r, \epsilon, \nu) = \gamma^2 \, (r^T r + \alpha^2 \epsilon^T \epsilon) - \nu^T \nu$ with finite L_2-gain γ is given by the matrix inequality:

$$Z = Z^T = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} & Z_{15} & Z_{16} \\ \cdot & Z_{22} & Z_{23} & Z_{24} & Z_{25} & Z_{26} \\ \cdot & \cdot & Z_{33} & Z_{34} & Z_{35} & Z_{36} \\ \cdot & \cdot & \cdot & Z_{44} & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot & Z_{55} & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & Z_{66} \end{bmatrix} < 0 \tag{4}$$

with

$$\begin{aligned} Z_{11} &= (A - FNH)^T P_{11} + P_{11}(A - FNH) \\ &\quad + H^T G^T P_{21} + P_{12} GH + \beta\beta^T \\ Z_{12} &= (A - FNH)^T P_{12} + H^T G^T P_{22} - P_{11} FM + P_{12} E \\ Z_{13} &= (A - FNH)^T P_{13} + H^T G^T P_{23} \\ &\quad + P_{11} DT + P_{13} R - \beta T \\ Z_{14} &= P_{11} B + k C^T \Lambda \\ Z_{15} &= P_{11} DU + P_{13} S - \beta U \\ Z_{16} &= P_{12} G - P_{11} FN \\ Z_{22} &= E^T P_{22} + P_{22} E - M^T F^T P_{12} - P_{21} FM \\ Z_{23} &= E^T P_{23} - M^T F^T P_{13} + P_{21} DT + P_{23} R \\ Z_{24} &= P_{21} B \\ Z_{25} &= P_{21} DU + P_{23} S \\ Z_{26} &= P_{22} G - P_{21} FN \\ Z_{33} &= R^T P_{33} + P_{33} R + T^T D^T P_{13} + P_{31} DT + T^T T \\ Z_{34} &= P_{31} B \\ Z_{35} &= P_{31} DU + P_{33} S + T^T U \\ Z_{36} &= P_{32} G - P_{31} FN \\ Z_{44} &= -2\Lambda \\ Z_{55} &= -\gamma^2 I + U^T U \\ Z_{66} &= -\alpha^2 \gamma^2 I. \end{aligned}$$

Proof: One checks the condition $\dot{\phi} - s \leq 0$ and applies the $\mathcal{S}$-procedure [1] using the sector condition on η, which gives $\dot{\phi} - s \leq \dot{\xi}^T P \xi + \xi^T P \dot{\xi} - 2\eta^T \Lambda(\eta - kCe) - s = \zeta^T Z \zeta < 0$. The quadratic form $\zeta^T Z \zeta$ is negative for all nonzero $\zeta = [e; \rho; \mu; \eta; r; \epsilon]$, provided Z is negative definite. □

According to [13], the nonlinear H_∞ synchronization problem seeks to find the linear dynamic output feedback controller $\mathcal{C}$ which minimizes the L_2-gain γ [15] with respect to the matrix inequality (4):

$$\min_{E,G,M,N,P,\Lambda,\gamma} \gamma \quad \text{such that} \quad Z(E, G, M, N, P, \Lambda, \gamma) < 0. \tag{5}$$

According to [13] we will consider binary valued continuous time reference inputs. For this class of signals perfect recovery of the message signal is obtained by implementing the operation $\mathrm{sign}(\beta^T e)$ [13]. The advantage with respect to the method described in [13] for secure communication applications is that the design based on (4) allows nonlinear H_∞ synchronization with transmission of one single signal.

V. Example: Chua's Circuit

For Chua's circuit [2], [9] we take the Lur'e representation $\dot{x} = Ax + B\varphi(Cx)$ [13] with

$$A = \begin{bmatrix} -2.5714 & 9 & 0 \\ 1 & -1 & 1 \\ 0 & -14.2860 & 0 \end{bmatrix}, \quad B = \begin{bmatrix} 3.8571 \\ 0 \\ 0 \end{bmatrix}, \quad C = [1 \quad 0 \quad 0] \tag{6}$$

and $\varphi(x_1) = \frac{1}{2}(|x_1 + 1| - |x_1 - 1|)$ a linear characteristic with saturation that belongs to sector $[0, 1]$. Possible keys for cryptographical purposes are the parameters of Chua's circuit and the matrix H, which linearly combines the state variables. The key scheme is different from previous work in [18]. In [18] a second state variable and the parameter set are used as keys. Here the usage of the linear transformation is twofold. First, it is well-known that a mixture

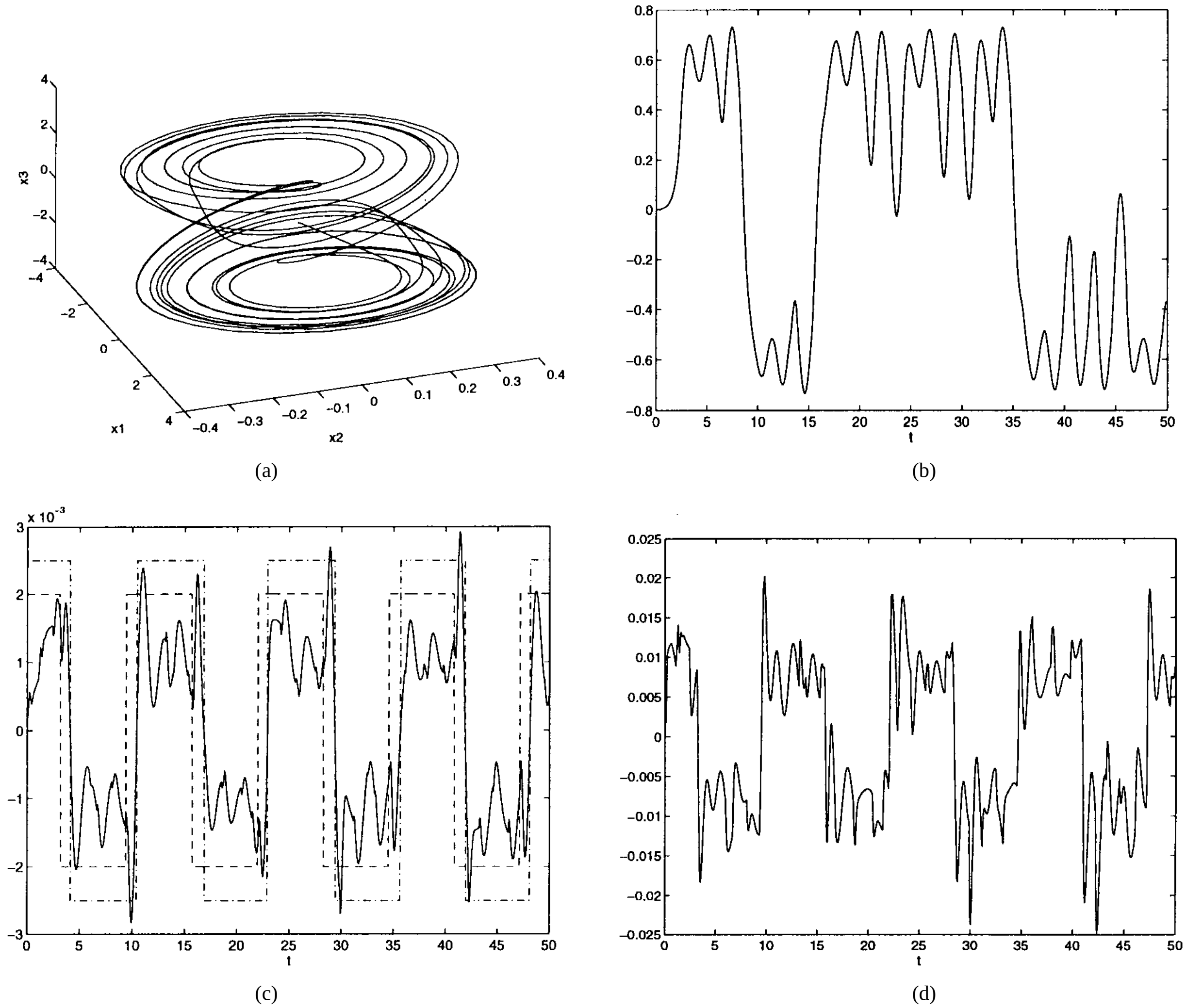

Fig. 1. Nonlinear H_∞ synchronization of Chua's circuit using linear dynamic output feedback: (a) Double scroll attractor generated at the master system.The vector field of the master system is modulated by means of the linearly filtered message signal $\mathrm{sign}(\cos(0.5t))$. (b) Transmitted signal, which is a linear combination of the state variables of the master Chua's circuit. The message signal is invisible on this transmitted signal. (c) $\beta^T e$ (-), reference input $\mathrm{sign}(\cos(0.5t))$ (- -), recovered message $\mathrm{sign}(\beta^T e)$ (-·). (d) control signal $u(t)$, applied to the slave system.

of more than one chaotic signal can provide a higher security to overcome the identification based attack as presented in [10], [11] and the characteristics based attack as presented in [19]. Second, the key H could be changed in order to avoid usage of the same key for a long time period. The security of the system is thereby improved.

In this example we take one-dimensional outputs p, q $(l = 1)$ with $H = [0.5; -0.5; 0.1]$ and a one-dimensional control signal u $(m = 1)$ with $F = [1; 0; 0]$. Furthermore $D = \beta = [1; 0; 0]$. For $\mathcal{R}$ a first order Butterworth filter is chosen with cut-off frequency 10 Hz. The nonlinear H_∞ synchronization problem (5) was solved by means of sequential quadratic programming [4] (*constr* in Matlab). The positive definite matrix P has been parameterized as $P = Q^T Q$ and

$$\min_{E,G,M,N,Q,\Lambda,\gamma} \gamma \quad \text{such that}$$
$$\lambda_{\max}[Z(E, G, M, N, Q, \Lambda, \gamma)] + \delta < 0 \qquad (7)$$

with $\delta = 0.01$ has been solved instead. In the supply rate $\alpha = 10$ is taken. We report the results here for a third order SISO controller. As starting point for the nonlinear optimization, random matrices were chosen for the controller according to a normal distribution with zero mean and standard variation 0.1, $Q = I_{n+n_c+n_r}$, $\Lambda = 0.1 I_{n_h}$, $\gamma = 100$. Suboptimal solutions to the nonconvex optimization problem yield satisfactory results. Fig. 1 shows simulation results obtained with this controller for a reference input $r = \mathrm{sign}(\cos(0.5t))$. The message signal is invisible on the transmitted signal. The original message is recovered by taking $\mathrm{sign}(\beta^T e)$. Simulations with zero mean white Gaussian noise for ϵ show that a standard deviation up to $1e$–04 for the noise is allowed in order to maintain perfect recovery. The robustness can be considerably improved by taking a smaller value for α in the supply rate. For $\alpha = 2$ a standard deviation of 0.1 is allowed for the noise.

VI. Conclusion

In this letter a new method for master–slave synchronization of Lur'e systems has been introduced. It combines two recently introduced ideas, nonlinear H_∞ synchronization [13] and synchronization by means of dynamic output feedback [14], in order to recover a class of message signals.

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REFERENCES

[1] S. Boyd, L. El Ghaoui, E. Feron, and V. Balakrishnan, *Linear Matrix Inequalities in System and Control Theory*, SIAM (Studies in Appl. Math.), vol. 15, 1994.

[2] L. O. Chua, "Global unfolding of Chua's circuit," *IEICE Trans. Fundament.*, vol. E76-A, no. 5, pp. 704–734, 1993.

[3] P. F. Curran and L. O. Chua, "Absolute stability theory and the synchronization problem," *Int. J. Bifurc. Chaos*, 1997, to be published.

[4] R. Fletcher, *Practical Methods of Optimization*. Chichester, U.K.: Wiley, 1987.

[5] M. Hasler, "Synchronization principles and applications," in *Circuits Syst.: Tutorials IEEE-ISCAS'94*, pp. 314–326.

[6] D. J. Hill and P. J. Moylan, "The stability of nonlinear dissipative systems," *IEEE Trans. Automat. Contr.*, vol. AC-21, pp. 708–711, 1976.

[7] ——, "Connections between finite-gain and asymptotic stability," *IEEE Trans. Automat. Contr.*, vol. AC-25, pp. 931–936, 1980.

[8] H. K. Khalil, *Nonlinear Systems*. New York: Macmillan, 1992.

[9] R. N. Madan, Guest Ed., *Chua's Circuit: A Paradigm for Chaos*. Signapore: World Scientific, 1993.

[10] K. M. Short, "Steps toward unmasking secure communications," *Int. J. Bifurc. Chaos*, vol. 4, no. 4, pp. 957–977, 1994.

[11] ——, "Unmasking a modulated chaotic communications scheme," *Int. J. Bifurc. Chaos*, vol. 6, no. 2, pp. 367–375, 1996.

[12] J. A. K. Suykens, J. P. L. Vandewalle, and B. L. R. De Moor, *Artificial Neural Networks for Modeling and Control of Non-Linear Systems*. Boston, MA: Kluwer Academic, 1996.

[13] J. A. K. Suykens, J. Vandewalle, and L. O. Chua, "Nonlinear H_∞ synchronization of chaotic Lur'e systems," *Int. J. Bifurc. Chaos*, vol. 7, no. 6, 1997.

[14] J. A. K. Suykens, P. F. Curran, and L. O. Chua, "Master-slave synchronization using dynamic output feedback," *Int. J. Bifurc. Chaos*, vol. 7, no. 3, pp. 671–679, 1997.

[15] A. van der Schaft, *L_2-Gain and Passivity Techniques in Nonlinear Control* (Lecture Notes in Control and Information Sciences 218.) New York: Springer-Verlag, 1996.

[16] J. C. Willems, "Dissipative dynamical systems I: General theory. II: Linear systems with quadratic supply rates," *Archive for Rational Mechan. Anal.*, vol. 45, pp. 321–343, 1972.

[17] C. W. Wu and L. O. Chua, "A unified framework for synchronization and control of dynamical systems," *Int. J. Bifurc. Chaos*, vol. 4, no. 4, pp. 979–989, 1994.

[18] T. Yang, C. W. Wu, and L. O. Chua, "Cryptography based on chaotic systems," *IEEE Trans. Circuits Syst. I*, vol. 44, no. 5, pp. 469–472, May 1997.

[19] T. Yang, "Recovery of digital signal from chaotic switching," *Int. J. Circuit Theory Applicat.*, vol. 33, no. 6, pp. 611–615, 1995.

A New Sufficient Condition for Nonsymmetric CNN's to Have a Stable Equilibrium Point

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***Abstract*—This letter gives a new sufficient condition for nonsymmetric CNN's to have at least one stable equilibrium point. Existence of a stable equilibrium point is important for nonsymmetric CNN's because it is a necessary condition for complete stability. It is shown that our sufficient condition is a generalization of a previous result concerning the existence of a stable equilibrium point, and that it can easily be applied to space-invariant CNN's with a 3 × 3 neighborhood.**

***Index Terms*—Cellular neural networks, complete stability, stable equilibrium points.**

I. INTRODUCTION

A cellular neural network (CNN) is a dynamic nonlinear circuit which has many applications in the field of image processing [3]. For proper operation in such applications a CNN must be completely stable in the sense that every trajectory tends to an equilibrium point. For symmetric CNN's it was proved in [2] and [13] that they are completely stable. On the other hand, for nonsymmetric CNN's only a few sufficient conditions for complete stability were given so far [4]–[6] in spite of the existence of some useful nonsymmetric feedback templates, such as the connected component detector [11].

The existence of a stable equilibrium point is an important criterion for complete stability because in order for nonsymmetric CNN's to be completely stable there must be at least one stable equilibrium point. Some sufficient conditions for the existence of a stable equilibrium point were given so far [1], [7], [8]. In [7] a sufficient condition for a two-dimensional infinite CNN to have at least one of four equilibrium configurations was given. In [8] the necessary and sufficient condition for a CNN to have equilibrium points in every region was given.

In this letter, we first give a new sufficient condition for nonsymmetric CNN's to have at least one stable equilibrium point. It is remarkable that our sufficient condition does not depend on the value of the constant input vector. Secondly, we show that our sufficient condition is a generalization of that given in [1]. Finally we apply it to the feedback template of space-invariant CNN's with a 3 × 3 neighborhood.

II. MAIN RESULTS

We deal with CNN's which can be defined by the following state equation:

$$\dot{x} = -x + Ay(x) + u \tag{1}$$

where $x = [x_1, x_2, \cdots, x_n]^T$ is the state vector, $A = [a_{ij}]$ is an $n \times n$ real matrix of which all diagonal elements are greater than 1, $u = [u_1, u_2, \cdots, u_n]^T$ is a constant input vector,

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