Computers & Industrial Engineering 102 (2016) 476–487

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Control and synchronization of chaotic supply chains using intelligent approaches

Uğur Erkin Kocamaz [a,*], Harun Taşkın [b], Yılmaz Uyaroğlu [c], Alper Göksu [b]

[a] Bahcelievler Dist., Guvercin St., No:16, Serdivan, Sakarya, Turkey
[b] Department of Industrial Engineering, Faculty of Engineering, Sakarya University, 54187 Serdivan, Sakarya, Turkey
[c] Department of Electrical & Electronics Engineering, Faculty of Engineering, Sakarya University, 54187 Serdivan, Sakarya, Turkey

ARTICLE INFO

Article history:
Available online 18 March 2016

Keywords:
Chaotic supply chain
Chaos control
Chaos synchronization
Artificial neural networks
Adaptive neuro-fuzzy inference system

ABSTRACT

This paper presents the control of chaotic supply chain with Artificial Neural Network (ANN) based controllers and the synchronization of two identical chaotic supply chains that have different initial conditions with Adaptive Neuro-Fuzzy Inference System (ANFIS) based controllers. A hybrid intelligent control model is designed in which the linear feedback and active control signals are also used for achieving the control and synchronization, respectively. ANN and ANFIS controllers are trained according to the model. Thereby, the advantages of classical and intelligent control methods are combined. Computer simulations show that the proposed approach is very effective for the control and synchronization of chaos in supply chain systems.

1. Introduction

Chaotic systems are nonlinear dynamical systems which have an infinite number of different periodic responses with sensitive dependence on initial conditions. Although chaos is sometimes a beneficial feature, it is often an undesirable phenomenon. The control is required for suppressing the chaotic oscillations. Besides, chaotic systems are likely to lead completely different trajectories because of slight errors. Therefore, chaotic systems may require synchronization. Since Ott, Grebogi, and Yorke (1990) successfully controlled a chaotic system, and Pecora and Carroll (1990) introduced the idea of synchronizing two identical chaotic systems, the control and synchronization of chaotic systems have become one of the major issues in the control engineering field. Various types of methods have been proposed and applied to the chaotic systems such as linear feedback control (Gambino, Lombardo, & Sammartino, 2006; Hegazi, Agiza, & El-Dessoky, 2001; Hwang, Hsieh, & Lin, 1997; Jianzu & Vincent, 1997; Kocamaz & Uyaroglu, 2014a; Wang & Wang, 2009), active control (Agiza & Yassen, 2001; Bai & Lonngren, 1997; Kocamaz & Uyaroglu, 2014b; Njah & Vincent, 2009; Ucar, Lonngren, & Bai, 2006), adaptive control (Li & Tong, 2013), sliding mode control (Feki, 2009), impulsive control (Li, Liao, Li, & Chen, 2006), passive control (Kocamaz & Uyaroglu, 2014a, 2014b; Wu, Liu, & Chen, 2008) and backstepping design (Yassen, 2007). Among them, the most preferred one for control is the linear feedback control method. It has been successfully implemented for the control of Lorenz (Jianzu & Vincent, 1997), Chua (Hwang et al., 1997), Rössler (Hegazi et al., 2001), Chen (Gambino et al., 2006), Liu (Wang & Wang, 2009), Rucklidge (Kocamaz & Uyaroglu, 2014a) and many other chaotic systems. For chaos synchronization, the active control is the most common method on account of its simplicity. It has been applied for the synchronization of Lorenz (Bai & Lonngren, 1997), Rössler (Agiza & Yassen, 2001), Chen (Agiza & Yassen, 2001), unified (Ucar et al., 2006), Bonhöffer–Van der Pol (Njah & Vincent, 2009), Vilnius (Kocamaz & Uyaroglu, 2014b) and many other chaotic systems. Artificial intelligence methodologies have also been proposed for chaos control and synchronization. The control of Lorenz (Guo, Lin, & Liu, 2006; Shen & Wang, 2007), Rössler (Yang, Zhang, & Zhang, 2009), Chen (Lu, Shieh, Chen, & Coleman, 2006), Lü (Yan & Liu, 2010), unified (Cheng & Tsai, 2010) chaotic systems and the synchronization of Lorenz (Chen, Jiang, Jiang, & Wu, 2009), Rössler (Chen et al., 2009; Lam & Seneviratne, 2007), unified (Cheng & Tsai, 2010), Genesio–Tesi (Ahn, 2010), Duffing–Holmes (Kuntanapreeda, 2010) and some other chaotic systems have been implemented by means of ANNs. Fuzzy logic, another popular intelligent technique, is used for the control of Lorenz (Harb & Smadi, 2004; Wu & Wang, 2007), Chua (Harb & Smadi, 2004; Zheng & Chen, 2009), Rössler (Zheng & Chen, 2009), Chen (Chang, Park, Joo, & Chen, 2003; Zheng & Chen, 2009), unified (Chen, Liu, & Tong, 2007), Mathieu–van der Pol (Li, 2011) chaotic systems and the synchronization of

* Corresponding author. Tel.: +90 535 970 2780; fax: +90 264 295 5601.
E-mail address: ugurkocamaz@gmail.com (U.E. Kocamaz).

http://dx.doi.org/10.1016/j.cie.2016.03.014
0360-8352/

Lorenz (Lam, Ling, Iu, & Ling, 2008; Yau & Shieh, 2008), Rössler (Lam et al., 2008), Chen (Lam et al., 2008), Duffing-Holmes (Yau & Shieh, 2008), Chua (Ababneh, Etier, Smadi, & Ghaeb, 2011), Rikitake (Vembarasan & Balasubramaniam, 2013) and some other chaotic systems. There are only a few papers on the control and synchronization of chaotic systems with ANFIS which is a combination of ANN and fuzzy logic systems (Bagheri & Moghaddam, 2009; Chen, 2009; Chen & Chen, 2009; Ginarsa, Soeprijanto, & Purnomo, 2013; Yeh, Chen, Lo, & Liu, 2011).

Supply chain aims to encounter the requirements of customers in correct location, on time, in correct amount, at necessary service level and with minimum cost. The enterprises require a supply chain to enhance their competitiveness. The phases of supply, production, distribution and retail should be given through to establish a supply chain (Chandra & Tumanyan, 2007). Over the past decade, many researchers paid their attentions to the issues of supply chain design, analysis, modelling, planning with a nonlinear viewpoint (Claypool, Norman, & Needy, 2014; Nasiri, Zolfaghari, & Davoudpour, 2014; Yang, Liu, & Yang, 2015). A number of studies show that supply chains have some imponderable factors in their dynamics and result in nonlinearity and chaotic activities (Donner, Scholz-Reiter, & Hinrichs, 2008; Fawcett & Waller, 2011; Lu, Tang, & Tang, 2004; Ramirez & Pena, 2011; Yuan & Hwarng, 2012). For example, supply chain planning and scheduling system, behavior of customers and purchasing decisions may lead to chaotic phenomenon in system components and at inventory levels under different phases. Bullwhip effect, in which demand distortion becomes larger when orders enhance, is one of the undesired nonlinear factors during the phases of supply chain. The usage of demand processing, order batching, lead times, supply shortages and price fluctuations are the major causes of bullwhip effect (Hwarng & Xie, 2008; Lee, Padmanabhan, & Whang, 1997). Uncertainty might be reduced by revealing the reasons of bullwhip effect in supply chain. Many researchers have tried to quantify, control and find the evidence of bullwhip effect in the real world of business, because they have great significance both theoretical and empirical objectives.

Chaotic cases at inventory levels and in production control mechanisms may cause some unwanted problems. The control of a supply chain system has great importance for eliminating its nonlinear behaviors and makes the demand, inventory and produced quantities as linear factors. The synchronization of supply chains leads the correct demand information might be retrieved by enterprise resource planning system on time even if it has chaotic trajectories. In the recent times, the control and synchronization of chaotic supply chains has been investigated in a few studies. The control of chaotic supply chain management system is realized by means of a linear feedback controller (Goksu, Kocamaz, & Uyaroglu, 2015). The chaos synchronization of bullwhip effect in a supply chain has been applied by using the radial basis function neural networks (Zhang, Li, & Xu, 2006). An adaptive feedback control model is proposed for the synchronization of chaos in supply chains to mitigate the effects due to uncertainties and perturbations (Anne, Chedjou, & Kyamakya, 2009). Recently, the synchronization of chaotic supply chain management systems has been achieved with the active control method (Goksu et al., 2015). In the literature, there has not been any published paper that implements the control of chaotic supply chain system with ANN approach or the synchronization of chaotic supply chain systems with ANFIS approach.

In this paper, the control and synchronization of chaotic supply chains are applied with intelligent approaches. ANN and ANFIS, which is a hybrid learning algorithm to identify the membership function parameters of Sugeno type Fuzzy Inference System (FIS) by training with the least-squared error and back-propagation gradient descent methods of ANNs, are used for the control and synchronization with including the linear feedback and active controllers, respectively. The rest of this paper is organized as follows: In the following section, brief descriptions of the chaotic supply chain system, ANN and ANFIS are given. Then, the linear

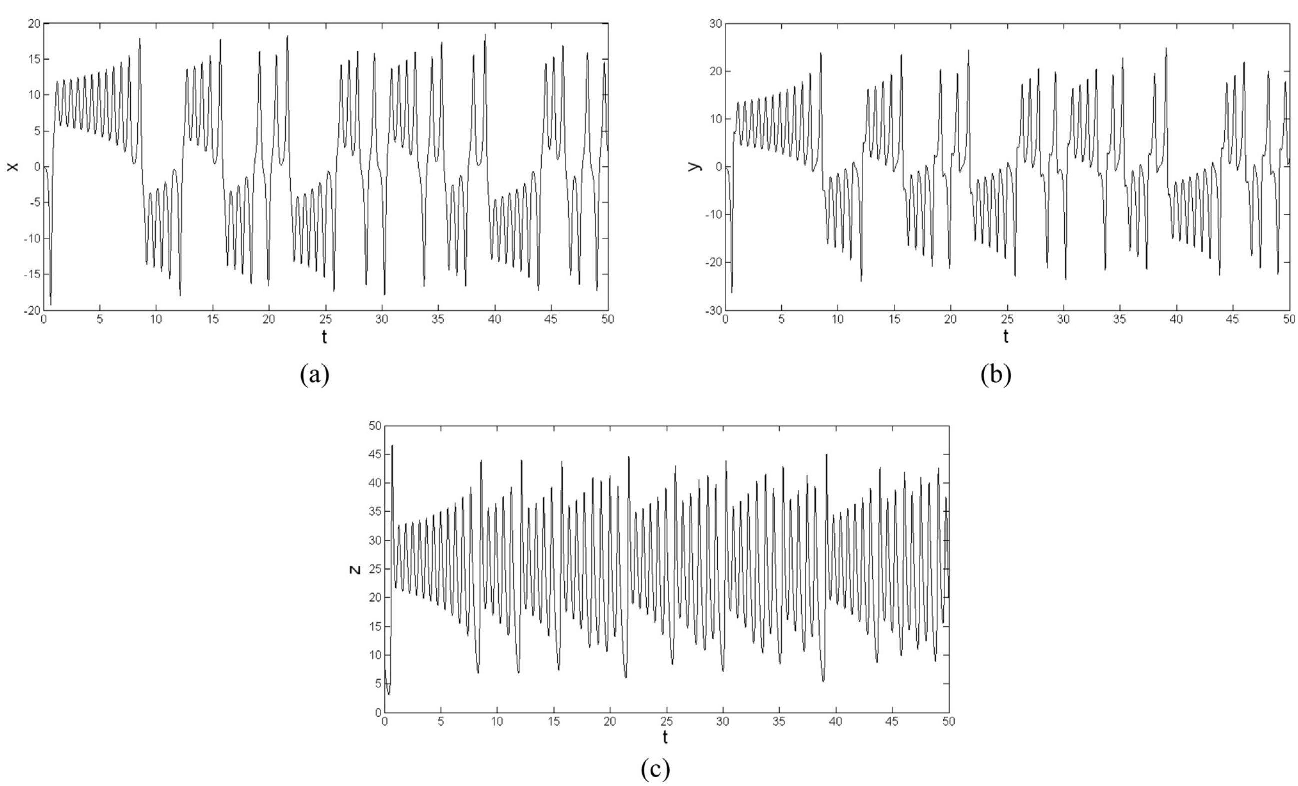

Fig. 1. Time series of chaotic supply chain system for (a) x, (b) y, and (c) z signals.