Chapter 16
Synchronization and Anti-Synchronization of Unidirectional and Bidirectional Coupled Chaotic Systems by Terminal Sliding Mode Control

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ABSTRACT

In this chapter, the synchronization and anti-synchronization of coupled unidirectional and bi-directional chaotic systems by terminal sliding mode control strategy are shown. The unidirectional synchronization consists in establishing a drive chaotic system and a response chaotic system in order to synchronize the variables of the response system in finite time. The unidirectional and bi-directional anti-synchronization consist in anti-synchronizing mutually a coupled chaotic system in both directions. For these purposes, terminal sliding mode control techniques are implemented. Three systems considered for experimental purposes in this study, a Lorenz, Rossler, and Ikeda systems are used for analysis and experimentation of synchronization and anti-synchronization. Three numerical experiments are shown to test the performance of the obtained proposed strategy.

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1 INTRODUCTION

Synchronization and anti-synchronization in chaotic systems have been thoroughly studied in recent years (Moaddy et al, 2011; Li et al., 2015; Mishra et. al., 2016; Khan et al., 2020a; Wang et al., 2017). These topics have many applications in the physical system, such as electrical, mechanical, optical and semiconductor applications and superconductivity. The synchronization of coupled chaotic systems, in its identical and non-identical forms, consists of a chaotic drive system and a chaotic response system in which the output of the second tracks the response of the first system. The case explained above is related to unidirectional synchronization, in bi-directional synchronization both systems are considered to be drive and response systems at the same time. Something similar happens in unidirectional and bi-directional anti-synchronization in which, in the first case, anti-synchronization is achieved in order to maintain the variables of the drive and response systems in the opposite direction. In the second case, anti-synchronization is achieved at the same time in both systems.

There are many examples in the literature concerning the synchronization of chaotic, unidirectional and bi-directional chaotic systems in their identical and non-identical form. For example, in Shahverdiev & Shore (2009), the synchronization of chaotic laser diodes in uni-directional and bi-directional forms is shown defining a dynamic model that describes the experimental setup and, later, the synchronization is performed using the appropriate technique. Shahverdiev et al. (2013) proposed the inverse chaos synchronization of coupled time delay chaotic systems. In Shahverdiev (2019), coupled junctions of Josephson and powered by a central junction are synchronized providing excellent application in the field of superconductivity. Another interesting example of chaos synchronization in bi-directional systems is found in Ji et al. (2008) where generalized chaos synchronization for bi-directional coupled differential equations is shown. In Khennaoui et al. (2019), an interesting example is given for the stabilization and synchronization of fractional order discrete time chaotic systems. An interesting application can be found in Sang et al. (2019) where a bi-directional synchronization control for an electro-hydraulic servo system is shown to prove another application of the theoretical context required for the design of synchronizers for chaotic systems. In Tarai et al. (2009), a synchronization of generalized linearly coupled two-way chaotic systems is shown in which a unified chaotic framework is implemented to solve this problem.

The synchronization and stabilization of various forms of chaotic systems such as fractional order or complex can be found also in some studies (Khennaoui et al., 2020; Ouannas et al., 2020a; Mittal et al., 2021). Vishal & Agrawal (2017) proposed a dynamic analysis control and synchronization of a new complex chaotic system. In Wembe & Yamapi (2009) synchronization of nonlinear bi-directional chaotic and hyperchaotic systems is achieved, given that hyperchaotic systems are more difficult to stabilize, an effective synchronization strategy is implemented in this analysis. Other examples can be found in Yuan et. al. (2012) where discrete time chaotic system synchronization is done bidirectionally. Another interesting application for chaos synchronization of chaotic systems can be found in Chen et al. (2020) where bi-directional synchronization of two Kuramoto systems is proposed. Also, in Deng et al. (2009), a bi-directional synchronization of semiconductor lasers by opto-electronic feedback, is proposed. Finally, in Zhou et al. (2007), hyper-chaotic systems in their linear and non-linear forms are synchronized.

There are many examples found in anti-synchronization literature. For example, the anti-synchronization of two non-identical chaotic systems is proposed by Al-Sawalha (2009). In Beregov & Melkikh (2015), two inductively coupled Van der Pol oscillators are de-synchronized. In Bao et al. (2020), a bi-directional chaotic communication configuration scheme based on wavelet-division-multiplexing WDM is implemented for semiconductor laser systems with time delay concealment. In Volos et al. (2011),