Chapter 10
Importance of Chaos Synchronization on Technology and Science

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ABSTRACT

In this chapter the authors talk about importance of chaos synchronization on technology and science. This chapter is developed in three sections. In the former the authors tackle the subject related with the so-called the synchronized state in the sense of identical synchronization. It is done via robust nonlinear observer design, considering corrupted measurements and model uncertainties, coupling uncertainty estimators with nonlinear state observers. The second part treats the subject related to the applications to chaos communications, that is to say, an application of chaos theory which is aimed to provide security in the transmission of information performed through telecommunications technologies, speaking roughly at the transmitter, a message is added on to a chaotic signal and then, the message is masked in the chaotic signal. As it carries the information, the chaotic signal is also called chaotic carrier. This is done via control theory and is a particular case of chaos synchronization. Finally, in the latter section the authors talk about application to synchronization of biological systems that is to say, the intercellular Ca^{2+} *waves have been seen like a mechanism by means of which a group of cells can communicate with one another and coordinate a multicellular response to a local event. Recently, it has been observed in a variety of systems that calcium signals can also propagate from one cell to another and thereby serve as a means of intercellular communication. The desire to understand the biophysical mechanisms of cellular dynamics has lead to introduce feedback control laws in some biological systems. Departing from the above ideas, this section explores links between feedback control schemes, with an external input, and intracellular calcium functions for coordination and control.*

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Synchronization of oscillations has been known to scientists since the historical observation of this phenomenon by Huygens in pendulum clocks. With the development of radio and electronics in the 20th century, synchronization occupied a very special place in science and technology. As many phenomena studied by nonlinear dynamics, synchronization was observed and shown to play an important role in many problems of a most diverse nature (physical, ecological, physiological, meteorological, and chemical to name a few). There is hardly a single communication or data storage application that does not rely on synchronization. Original notion and theory of synchronization implies periodicity of oscillators (Pecora, 1990; Pecora, 1998).

The discovery of deterministic chaos introduced a new kind of an oscillating system, a chaotic generator. Chaotic oscillations are found in many dynamical systems of various origins. The behavior of such systems is characterized by instability of bounded trajectories and, as a result, limited predictability along time. Intuitively it would seem that chaos and synchronization are two mutually exclusive terms. Synchronization of chaos is a phenomenon that may occur when two, or more, chaotic oscillators are coupled (namely complex networks), or when a chaotic oscillator drives another chaotic oscillator, namely, master-slave synchronization. Yet it has been shown that synchronization can be observed even in chaotic systems. However, the special features of chaotic systems make it impossible to directly apply the methods developed for synchronization of periodic oscillations. Although synchronization has been observed in chaotic systems, particular properties of chaos provoke synchrony methods of periodic oscillators cannot be applicable on chaos. Even defining the notion of synchronization for chaotic systems is difficult without running into a paradox or controversy.

Clear understanding of chaos synchronization phenomena and dynamical mechanisms behind it open new opportunities both for applications of chaotic signals in engineering and for understanding functionality of neurobiological networks, where irregular (chaotic) dynamics of neurons occurs naturally. This research activity focuses on the developments of theoretical foundations for chaos synchronization based on the experimental studies of synchronization phenomenon in physical, neurobiological and other systems.

From the above, in this book chapter proposal, there are considered several cases for chaos synchronization, in particular:

- **Identical master-slave synchronization.** This is a straightforward form of synchronization that may occur when two identical chaotic oscillators are mutually coupled, or when one of them drives the other. Although synchronization has been observed in chaotic systems, particular properties of chaos provoke synchrony methods of periodic oscillators cannot be applicable on chaos. Consider $(x_1,x_2,\ldots,x_n)$ and $(x'_1, x'_2,\ldots,x'_n)$ denote the set of dynamical variables that describe the state of the first and second oscillator, respectively, it is said that identical synchronization occurs when there is a set of initial conditions $[x_1(0), x_2(0),\ldots,x_n(0)]$, $[x'_1(0), x'_2(0),\ldots,x'_n(0)]$ such that, denoting the time by t, $|x'_i(t)-x_i((t)|\to 0$, for $i=1,2,\ldots,n$, when $t\to\infty$. That means that for time large enough the dynamics of the two oscillators verifies $x'_i(t)=x_i(t)$, for $i=1,2,\ldots,n$, in a good approximation. This is called the synchronized state in the sense of identical synchronization. It is done vía robust nonlinear observer design, considering corrupted measurements and model uncertainties, coupling uncertanty estimators with nonlinear state observers.
- **Applications to chaos communications** is an application of chaos theory which is aimed to provide security in the transmission of information performed through telecommunications technologies. By secure communications, one has to understand that the contents of the message transmit-

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