Preface

The study of time series has traditionally been within the realm of statistics. A large number of both theoretical and practical algorithms have been developed for characterizing, modeling, predicting and filtering raw data. Such techniques are widely and successfully used in a broad range of applications, e.g., signal processing and communications. However, statistical approaches use mainly linear models, and are therefore unable to take advantage of recent developments in nonlinear dynamics. In particular, it is now widely accepted that even simple nonlinear deterministic mechanisms can give rise to complex behavior (i.e., chaos) and hence to complex time series. Conventional statistical time-series approaches are unable to model or predict complex time series with a reasonable degree of accuracy. This is because they make no use of the fact that the time series has been generated by a completely deterministic process, and hence ascribe most of the complexity to random noise. Furthermore, such approaches cannot yield much useful information about the properties of the original dynamical system.

Fortunately, a remarkable result due to Takens shows that one can reconstruct the dynamics of an unknown deterministic finite-dimensional system from a scalar time series generated by that system. Takens' theorem is actually an extension of the classical Whitney's theorem. It is thus concerned with purely deterministic autonomous dynamical systems and the framework that it provides for time series analysis is unable to incorporate any notion of random behavior. This means that the process of reconstruction is outside the scope of statistical analysis because any such analysis would require a stochastic model of one kind or another as its starting point. This is reflected in common practice, where reconstruction is seen as a straightforward algorithmic procedure that aims to recover properties of an existing, but hidden, system.

The problem of reconstructing signals from noisy corrupted time series arises in many applications. For example, when measurements are taken from a physical process suspected of being chaotic, the measuring device introduces error in the recorded signal. Alternatively, the actual underlying physical phenomenon may be immersed in a noisy environment, as might be the case if one seeks to detect a low-power (chaotic) signal (possibly used for communications) that has been transmitted over a noisy and distorted channel. In both cases, we have to attempt to purify or detect a (chaotic) signal from noisy and/or distorted samples.

Separating a deterministic signal from noise or reducing noise in a noisy corrupted signal is a central problem in signal processing and communications. Conventional methods such as filtering make use of the differences between the spectra of the signal and noise to separate them, or to reduce noise. Most often the noise and the signal do not occupy distinct frequency bands, but the noise energy is distributed over a large frequency interval, while the signal energy is concentrated in a small frequency band. Therefore, applying a filter whose output retains only the signal frequency band reduces the noise considerably. When the signal and noise share the same frequency band, the conventional spectrum-based methods are no longer applicable. Indeed, chaotic signals in the time domain are neither periodic nor quasi-periodic, and appear in the frequency domain as wide "noise-like" power spectra. Conventional techniques used to process classic deterministic signals will not be applicable in this case.

Since the property of self-synchronization of chaotic systems was discovered in 1990 by Pecora and Carroll, chaos-based communications have received a great deal of attention. However, despite some inherent and claimed advantages, communicating with chaos remains, in most cases, a difficult problem. The main obstacle that prevents the use of chaotic modulation techniques in real applications is the very high sensitivity of the demodulation process. Coherent receivers which are based on synchronization suffer from high sensitivity to parameter mismatches between the transmitter and the receiver and even more from signal distortion/contamination caused by the communication channel. Non-coherent receivers which use chaotic signals for their good decorrelation properties have been shown to be more robust to channel noise; however, as they rely mainly on (long-term) decorrelation properties of chaotic carriers, their performances are very close to those of standard non-coherent receivers using pseudo-random or random signals. In both cases, coherent and non-coherent, it has been shown that noise reduction (or signal separation) can considerably improve the performance of chaos-based communication systems.

The aforementioned problems can be conveniently tackled if signals can be reconstructed at the receiving end. Motivated by the general requirements for chaotic signal processing and chaos-based communications, this book addresses the fundamental problem of reconstruction of chaotic signals under practical communication conditions.

Recently, it has been widely recognized that artificial neural networks endow some unique attributes such as universal approximation (input-output mapping), the ability to learn from and adapt to their environments, and the ability to invoke weak assumptions about the underlying physical phenomena responsible for the generation of the input data. In this book, the technical approach to the reconstruction problem is based on the use of neural networks, and the focus is the engineering applications of signal reconstruction algorithms.

We begin in Chapter 1 by introducing some background information about the research in signal reconstruction, chaotic systems and the application of chaotic signals in communications. The main purpose is to connect chaos and communications, and show the potential benefits of using chaos for communications. In Chapter 2 we will review the state of the art in signal reconstruction, with special emphasis laid on deterministic chaotic signals. The Takens' embedding theory will be reviewed in detail, covering the salient concepts of reconstructing the dynamics of a deterministic system from a higher-dimensional reconstruction space. The concepts of embedding dimension, embedding lag (time lag), reconstruction function, etc., will be discussed. Two basic embedding methods, namely topological and differential embeddings, will be described. Some unsolved practical issues will be discussed. A thorough review of the use of neural networks will be given in Chapter 3. Two main types of neural networks will be described in detail, namely, the radial-basis-function neural networks and the recurrent neural networks. The background theory, network configurations, learning algorithms, etc., will be covered. These networks will be shown suitable for realizing the reconstruction tasks in Chapters 7 and 8. In Chapter 4 we will describe the reconstruction problem when signals are transmitted under ideal channel conditions. The purpose is to extend the Takens' embedding theory to time-varying continuous-time and discrete-time systems, i.e., nonautonomous systems. This prepares the readers for the more advanced discussions given in the next two chapters. In Chapter 5, we will review the Kalman filter (KF) and the extended Kalman filter (EKF) algorithms. In particular, we will study a new filter, i.e., the unscented Kalman filter (UKF). The issue for filtering a chaotic system from noisy observation by using the UKF algorithm will be investigated. A lot of new finding of the UKF algorithm will be demonstrated in this chapter. In Chapter 6, we will apply the UKF algorithm to realize the reconstruction of chaotic signals from noisy and distorted observation signals, respectively. Combining the modeling technique for signal with the UKF algorithm, the original UKF algorithm will be expanded to filter time-varying chaotic signals. We will also address the issues of blind equalization for chaos-based communication systems. Our start point is to make use of the UKF algorithm and the modeling technique for signal, and to realize a blind equalization algorithm. In Chapter 7 we will present novel concepts of using a radial-basis-function neural network for reconstructing chaotic dynamics under noisy condition. A specific adaptive training algorithm for realizing the reconstruction task will be presented. Results in terms of the mean-squared-error versus the signal-to-noise ratio will be given and compared with those obtained from conventional reconstruction approaches. Also, as a by-product, a non-coherent detection method used in chaos-based digital communication systems will be realized based on the proposed strategy. In Chapter 8 we will continue our discussion of signal reconstruction techniques. Here, we will discuss the use of a recurrent neural network for reconstructing chaotic dynamics when the signals are transmitted through distorting and noisy channels. A special training algorithm for realizing the reconstruction task will be presented. This problem will also be discussed under the conventional viewpoint of channel equalization. In Chapter 9, the reconstruction of chaotic signals will be considered in terms of chaos synchronization approaches. In particular, the problem of multiple-access spread-spectrum synchronization for single point to multiple point communication is considered in the light of a chaotic network synchronization scheme, which combines the Pecora-Carroll synchronization scheme and the OGY control method. The results indicate that such a network synchronization scheme is applicable to fast synchronization of multiple chaotic systems, which is an essential condition for realizing single point to multiple point spread-spectrum communications. Simulation results indicate that such a network synchronization-based communication system is effective and reliable for noisy and multi-path channels. The final chapter summarizes the key results in this research.

In closing this preface, we hope that this book has provided a readable exposition of the related theories for signal reconstructions as well as some detailed descriptions of specific applications in communications. We further hope that the materials covered in this book will serve as useful references and starting points for researchers and graduate students who wish to probe further into the general theory of signal reconstruction and applications.

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