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Synchronization and Control of Chaos:
Theory, Methods and Applications

Preface

In the last few decades, Chaos theory has become a very important and active research field, employing many applications in different disciplines like physics, chemistry, biology, ecology, engineering and economics, among others. Its scope is based on scientific studies associated with the search on behavior of nonlinear dynamical systems, which are highly sensitive to their initial conditions, and known as *chaotic systems*. The sensitivity to initial conditions of a chaotic system is usually referred to as *butterfly effect*. In due course of time, several kinds of sub-working fields have also been introduced within the context of research studies on Chaos theory.

Chaos control and chaos synchronization are some sub-working fields that can be examined within the mentioned content. Chaos control and chaos synchronization are especially remarkable and important research fields aiming to affect dynamics of chaotic systems in order to use them for different kinds of applications that can be examined within many different fields like computer sciences, mechanics, communication, economics and finance, biology, chemistry, medicine, geology, among others.

Currently, there are different kinds of approaches or methods that have been proposed for performing chaos control and chaos synchronization tasks. But because of some disadvantages and limitations of these ones, newer approaches or methods are designed and introduced by researchers to improve the related works within the field. Additionally, there are also many studies already introduced in order to improve more advanced solutions for problems of chaos control and chaos synchronization. Most of these studies include usage of intelligent approaches or systems on the related problems of the Chaos theory.

So, this Special Issue contains important scientific papers that will stimulate the continuing efforts to understand the nature of control and synchronization of nonlinear systems. These articles present theoretical, numerical and experimental studies on novel chaos synchronization and control methods, as well as research on their new applications.

In the first paper, Dr. Sampath *et al.* propose an eight-term novel four-scroll chaotic system with cubic nonlinearity. They analyse its fundamental properties such as dissipativity, equilibria, symmetry and invariance, Lyapunov exponents and Kaplan-Yorke dimension. Also, an electronic circuit realization of the novel four-scroll chaotic system is presented by using SPICE to confirm the feasibility of the proposed theoretical model.

The delayed feedback control of Bao chaotic system based on Hopf bifurcation analysis is studied by Dr. Farhad Khellat. In this work, the condition that the system has a Hopf bifurcation is derived. Then by applying delayed feedback controller, the chaotic system is forced to have a stable periodic orbit extracting from chaotic attractor. This is done by making Hopf bifurcation value of the open loop and the closed loop systems identical. Also by suitable tuning of the controller parameters, unstable equilibrium points become stable.

The study of the spectral properties of chaotic signals generated by the well-known Bernoulli map is presented by Dr. Rafael da Costa *et al*. They obtain analytic expressions for autocorrelation sequence, PSD and essential bandwidth for chaotic orbits generated by this map as function of the family parameter and Lyapunov exponent. Moreover, they verify that analytical expressions match numerical results and conclude that the power of the generated orbits is concentrated in low frequencies for all parameters values.

Furthermore, the adaptive synchronization of memristor-based chaotic neural systems has been studied in the paper presented by Dr. Xiaofang Hu and Dr. Shukai Duan. Simulation results have demonstrated the effectiveness of the proposed adaptive synchronization method and its potential in practical application of memristive chaotic oscillators in secure communication.

The next paper, written by Dr. Vaidyanathan *et al.*, presents the analysis, adaptive control and anti-synchronization of a six-term novel Jerk chaotic system with two exponential nonlinearities. The controller is based on the adaptive backstepping method, which is used to stabilize the novel Jerk chaotic system having two unknown parameters. Moreover, an adaptive backstepping controller is designed to achieve global chaos anti-synchronization of two identical novel Jerk chaotic systems with two unknown system parameters.

Dr. Hanjie Gu and Fan Wu work on the very interesting subject of noise separation from the weak signal detection chaotic system. In more details, this paper proposed a novel weak signal chaotic detection system based on an improved wavelet transform algorithm, which is applied in the weak signal chaotic detection system. The noise signal after finite discrete processing is treated as a perturbation of cycle power and put into a chaotic system for detecting weak signal under the noise conditions. The simulation results show that the proposed improved wavelet transform algorithm has a better denoising effect than the traditional wavelet transform algorithm.

Also, in the next paper, an interesting case of unidirectional coupling between identical Chua circuits via an HP memristor is proposed by Dr. Christos Volos *et al*. The simulation results show a variety of dynamical phenomena, such as chaotic synchronization and on-off intermittency, depending on memristor's initial state and the parameters of the chosen window function.

A 3-D novel conservative chaotic system and its generalized projective synchronization via an adaptive control are presented by Dr. Vaidyanathan and Dr. Pakiriswamy. In more details, this research work discusses the qualitative properties of the proposed system, while an adaptive controller is designed to achieve generalized projective synchronization of two identical novel chaotic systems with unknown system parameters. MATLAB simulations are shown to validate and demonstrate the results derived in this work.

Furthermore, Dr. Zhen Xu presents the optimization of parameters estimation in chaotic control scheme by using a new estimation model based on improved particle swarm optimization algorithm. This model firstly constrains the search space of the population with Tent and Logistic double mapping to regulate the initialized population size, optimizes the fitness value by evolutionary state identification strategy so as to avoid its premature convergence, optimizes the inertia weight by the nonlinear decrease strategy to reach better global and local optimal solution, and then optimizes the iteration of particle swarm optimization algorithm with the hybridization concept from genetic algorithm. Next, this method is applied into the parameter estimation of chaotic systems control. Simulation results show that the proposed parameter estimation model shows higher accuracy, anti-noise ability and robustness compared with the model based on standard particle swarm optimization algorithm.

Dr. Sarkar and Dr. Chakraborty study the phenomenon of chaotic oscillations in a third order PLL in the face of two co-channel signals as well as its control scheme. A third order phase locked loop incorporating a resonant type second order filter is a conditionally stable system and shows complicated dynamics including chaotic oscillations for a range of loop parameters. In the face of two co-channel signals, an otherwise stable loop may be thrown into a chaotic state, depending on the relative strength and mutual frequency offset of the input signals. The authors have predicted the parameter zone for chaotic state of the loop through numerical studies and verified the prediction by hardware experiment. Then they modify the loop structure to incorporate an additional control signal which stabilizes the loop dynamics and removes the chaotic oscillations. The improved response of the loop is established numerically and experimentally.

Furthermore, Dr. Vaidyanathan *et al.* present an adaptive backstepping controller design for the anti-synchronization of identical Wind-Magnetosphere-Ionosphere (WINDMI) chaotic systems with unknown parameters. The adaptive controller design for the anti-synchronization of identical WINDMI systems with unknown parameters has been established by applying Lyapunov stability theory. MATLAB simulations have been performed for the illustration of the adaptive anti-synchronizing backstepping controller for identical WINDMI chaotic systems. Finally, the proposed controller has been implemented using SPICE and circuit simulation results have been detailed.

Dr. JianWei Lin and Dr. Zibin Xu present an accuracy optimization of synchronization parameters in chaotic time series prediction. This method is used to construct the initial population of genetic algorithm to speed up the convergence and then prescribes a limit to the objective function with improved punishment function. Then it optimizes the crossover, mutation and duplication operators of the genetic operator to avoid the premature convergence. Moreover, it adopts the complex method to optimize the local optimization ability of the standard genetic algorithm on the basis of improved fitness function. Next, this paper applies the improved algorithm into the synchronous parameters optimization of chaotic time series prediction model.

The design of secure communication schemes, by using coupled chaotic systems is presented by Dr. Aceng Sambas *et al.* In this paper, the case of bidirectional coupling of chaotic Jerk systems, as the main component of a secure communication scheme is investigated.

Dr. Komeil Nosrati *et al.* present a novel chaotic communication method by using an Unscented Kalman Filter (UKF). The main highlighted advantages of using UKF are increasing accuracy, efficiency and improvement of synchronization's time. Encoding chaotic communication achieves a satisfactory, typical secure communication scheme. To illustrate the effectiveness of the proposed scheme, a numerical example based on the Lorenz and Rössler dynamical systems is presented and the results are compared to the Extended Kalman Filter (EKF).

In the next paper Dr. Vaidyanathan studies a 3-D novel highly chaotic system with four quadratic nonlinearities, its adaptive control and anti-synchronization with unknown parameters. The Lyapunov exponents of the 3-D novel chaotic system are obtained as $L_1 = 11.36204$, $L_2 = 0$ and $L_3 = -47.80208$. Since the sum of the Lyapunov exponents is negative, the 3-D novel chaotic system is dissipative. Also, the Kaplan-Yorke dimension of the 3-D novel chaotic system is obtained as $D_{KY} = 2.23769$. The maximal Lyapunov exponent (MLE) of the novel chaotic system is $L_1 = 11.36204$, which is a large value for a polynomial chaotic system. Thus, the proposed 3-D novel chaotic system is highly chaotic.

The prediction accuracy optimization of chaotic perturbation in the analysis model of network-oriented consumption is presented by Dr. Dakai Li and Dr. Li Yu. Simulation results show that the proposed network-oriented consumption analysis neural network model based on chaotic disturbance optimized particle swarm has greatly improved in prediction accuracy and computational speed.

In the next paper, a new noncoherent chaotic modulation technique, based on adaptive decision threshold, is proposed for the Ultra-WideBand Direct Chaotic Communication (UWB DCC) technology is proposed by Dr. S. Sadoudi *et al.* The principal advantages of the proposed technique are: (1) Removing the threshold problem of the classical Chaotic On-Off Keying modulation technique which uses a nonzero decision threshold; (2) Providing a high throughput comparing to the others techniques since it do not uses any delay at the modulation; (3) Reducing the transmitted power, thanks to a transmitted bit energy devised by two. The obtained simulation results show high Bit Error Rate performances of the proposed technique applied in an UWB DCC system. In addition, the new chaotic modulation is more suitable in all DCC-based communications schemes.

The analysis, adaptive control and synchronization, have been studied by Dr. Vaidyanathan *et al.*, in the case of a seven-term novel 3-D chaotic system with three quadratic nonlinearities. Also, an electronic circuit realization of the novel chaotic system is depicted using LabVIEW to confirm the feasibility of the theoretical chaotic model.

The study of the dynamical behavior as well as coupling schemes via the recently new proposed nonlinear element (memristor) is investigated in the next paper. In more details, Dr. Christos Volos *et al.* present in their paper a variety of dynamical phenomena, such as periodic, quasi-periodic and chaotic behaviors, as well as anti-phase and complete synchronization phenomena, depending on the value of the coupling coefficient, in the case of coupled Colpitts circuits.

An interesting approach related with a neural synchronization scheme by using genetic approach for secure key generation is studied by Dr. Daxing Wang. Neural cryptography is a way to create shared secret key. Key generation in Tree Parity Machine neural network is done by mutual learning. Neural networks here receive common inputs and exchange their outputs. Adjusting discrete weights according to a suitable learning rule then leads to full synchronization in a finite number of steps and these identical weights are the secret key needed for encryption. A faster synchronization of the neural network has been achieved by generating the optimal weights for the sender and receiver from a genetic process.

In the next paper, Dr. Christos Volos *et al.* use a flux-controlled memristor model, which is adopted for using as a coupling element between coupled neuromorphic circuits. In this work, the latest achievements and applications of this newly development circuit element are presented. Also, the basic features of neuromorphic circuits, in which the memristor can be used as an electrical synapse, are studied. So, the flux-controlled memristor model is adopted for using as a coupling element between coupled electronic circuits, which simulate the behavior of neuron-cells. For this reason, the circuits which are chosen realize the systems of differential equations that simulate the well-known Hindmarsh-Rose and FitzHugh-Nagumo neuron models.

The analysis, adaptive control and adaptive synchronization of a nine-term novel 3-D chaotic system with four quadratic nonlinearities is presented by Dr. Vaidyanathan Dr. Volos and Dr. Pham. The phase portraits of the 3-D novel chaotic system simulated using MATLAB, depict the strange chaotic attractor of the system.

The synchronization scheme of coupled generalized Chua's chaotic oscillators in a small-world topology is studied by Dr. Soriano-Sánchez *et al.* Authors resort to existing information about that long-range connection in a network increases the data flow from one unit to another to achieve synchronization under a small fixed coupling strength. Computer simulations are provided to show this chaos synchronization based on complex systems theory.

Also, Dr. Amir Hossein Abolmasoumi and Dr. Somayeh Khosravivejad study the case of chaos control in memristor-based oscillators by using intelligent sliding mode control scheme. In order to gain stabilization and tracking of a sinusoidal input, an appropriate sliding surface is proposed and sliding gain is tuned. Also, to avoid the chattering phenomenon in traditional sliding mode controller and to reduce the hitting time of the controlled system, an especial genetic algorithm optimization method is suggested. By defining a new objective function and searching for optimal the controller parameters the convergence time and chattering are reduced considerably. The usefulness of the proposed controller with intelligent tuning method for chaos control of memristor-based oscillators is demonstrated in memristor-based Chua's circuit.

In the next paper, Dr. Yanyan Gao and Dr. Guoliang Huang study the corporate investment dynamic control system based on chaos cycle perturbations. In more details, this paper presents a predictive model of business investment based on improved artificial bee colony and chaos periodic disturbance optimizing BP neural network algorithm. At first, the Boltzmann selection strategy and group behavior control strategy to optimize the artificial bee colony algorithm is used and then the improved algorithm to transform BP neural network algorithm's optimized parameters into optimization process of artificial bee colony algorithm to reduce the training error of the original algorithm is applied.

Dr. Pham *et al.* present a novel hyperchaotic memristor-based system with hidden attractors as well as its dynamics, its circuital emulating and a synchronization scheme of two coupled memristors of this type. The dynamics properties of this hyperchaotic system are discovered through equilibria, Lyapunov exponents, bifurcation diagram, Poincaré map and limit cycles. In addition, its anti-synchronization scheme via adaptive control method is also designed and MATLAB simulations are shown. Finally, an electronic circuit emulating the memristor-based hyperchaotic system has been designed using off-the-shelf components.

Furthermore, the design of an adaptive output feedback control for a class of uncertain nonlinear systems using only one single-hidden-layer neural network in order to eliminate the unstructured uncertainties is presented in the paper of Dr. Ait Abbas Hamou *et al.* The approach employs feedback linearization, coupled with an on-line neural network to compensate for modelling errors. A fixed structure dynamic compensator is designed to stabilize the linearized system. A signal, comprised of a linear combination of the measured tracking error and the compensator states, is used to adapt the neural network weights. The network weight adaptation rule is derived from Lyapunov stability analysis, and guarantees that the adapted weight errors and the tracking error are bounded. Numerical simulations of both nonlinear systems, Van der Pol example and tunnel diode circuit model, having full relative degree, are used to illustrate the practical potential of the proposed approach.

Dr. Yanping Tang and Dr. Guanghui Li present an interesting application of control in the sports training chaos predicting model. This paper, firstly uses the comprehensive weight factor to perform the weight control to the initial information of the new join node in the ant colony algorithm, and then performs the optimizing iteration to the pheromone of weight control optimization, and updates the pheromone of ant node according to its contribution. Then the paper performs the optimization selection to the pheromone persistence parameters, the normalized factors and the relative importance factors to reduce the computing time and optimal error rate of the ant colony algorithm.

In the last paper the analysis, control and synchronization of a novel 4-D hyperchaotic Rikitake dynamo system without equilibrium is presented by Dr. Vaidyanathan *et al*. In more details, this work announces a novel 4-D hyperchaotic Rikitake dynamo system, which is derived by adding a state feedback control to the famous 3-D Rikitake two-disk dynamo system. The qualitative properties of the proposed hyperchaotic Rikitake dynamo system, which has no equilibrium points, are discussed. Next, this paper presents the control and synchronization of the novel hyperchaotic Rikitake dynamo system with unknown parameters using adaptive control method. The main results are established using Lyapunov stability theory and numerically illustrated using MATLAB. Finally, for the 4-D novel hyperchaotic system, an electronic circuit realization in SPICE has been described to confirm the feasibility of the theoretical hyperchaotic Rikitake dynamo model.

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Dr. Sundarapandian Vaidyanathan
Professor and Dean at the Research and Development Centre,
Vel Tech University, India

Dr. Esteban Tlelo-Cuautle
Professor-Researcher at the Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), México

Dr. Viet-Thanh Pham
Lecturer at the School of Electronics and Telecommunications, Hanoi University of Science and Technology, Vietnam

Dr. Christos Volos
Lecturer at the Physics Department, Aristotle University of Thessaloniki, Greece