Sample entropy of GPi neurons dependence on the level of alertness in 6OHDA rats

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Abstract

The analysis of neuronal data obtained during functional neurosurgery from alert human patients with Parkinson's disease, raised the question to what extent the increase in the entropy of single parkinsonian *Basal ganglia* (BG) neurons depends on the level of consciousness and to what on the disease itself. Here, we assess the dependence of sample entropy on the level of alertness in healthy and parkinsonian rats. To this end, we separated thirty-six adult Sprague-Dawley rats randomly to two groups: control and 6OHDA-lesioned animals. Between 21 and 28 days after the lesion procedure, animals underwent behavioral evaluation with the cylinder test to confirm asymmetry in limb-force and went through stereotactic surgery with the objective of registering spontaneous activity of the medial Globus Pallidum (GPi). Animals were placed in an ad-hoc built restraining device that did not allow any spontaneous movements during the whole recording time. The eyes of the animals were covered; all recordings were obtained in conditions of environmental silence. The alertness level was characterized periodically with a standardized non-painful stimulus. From 38 *GPi* single-neuron recordings that were obtained during the awakening process in relaxed, head-restrained, control and 6OHDA-lesioned rats, we found that the sample entropy increased in the 6OHDA group with an increasing level of alertness, but it was reduced in the control group. While increasing the level of alertness, single neurons changed their behavior adaptively, showing that the measured characteristics should be considered as emergent properties of the state of the neural system rather than static, intrinsic electrophysiological properties of GPi neurons. We interpret the observed increase in the level of entropy of parkinsonian neurons as the inability of dopamine-depleted Basal Ganglia to handle augmented levels of input that are associated with higher levels of alertness. A relevant conclusion for the analysis of experimental data is that an extrapolation from data obtained under anesthesia to the wake subject or animal is bound to lead to incorrect results.

Controlling the system with hyperbolic attractor

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For a long time it was a common opinion that hyperbolic attractors are artificial mathematical constructions [1]. However, in the recent papers [2, 3] there were proposed physically realizable systems that possess, in their phase space, the set with features that are very similar to hyperbolic type of attractors. As is known, invariant sets are called hyperbolic attractors of the dynamical system if they are closed, topologically transitive subsets, and every their trajectory possesses uniform hyperbolicity. Very familiar types of the hyperbolic attractors are Smale-Williams' solenoid and Plykin's attractor.

Further, it is well known that chaotic systems are very sensitive to the external perturbations. This property is used for controlling nonlinear systems and chaos suppression. Thus, an important question arises: Is it possible to suppress chaos in systems with hyperbolic attractors because these attractors are structurally stable subsets?

In the present contribution we study the possibility of stabilization of chaotic oscillations in systems with the Smale-Williams hyperbolic attractors by means of periodic forcing and the Pyragas method with a delay [4]. It is shown that in both cases the dynamical system could be controllable: the hyperbolic attractor degenerates into a periodic one.

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A feedback suppression of traveling waves in an excitable medium with parameter uncertainty

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It is well known that blood in a body is circulated by periodic electronic activation in cardiac tissue; however, the ability of the heart to pump blood is reduced by irregular activation, such as ventricular tachycardia and ventricular fibrillation. This irregular activation, which induces a major health problem, is described as the spatial waves and spatiotemporal chaos in excitable media [1]. The only current treatment for eliminating the activation is to apply a *high*-voltage electric shock to the patient's chest. Unfortunately, this treatment often causes physical and mental strain to the patient; there are great hopes to put a *low*-voltage electric shock into practical use [2].

As the electric shock for the elimination corresponds to a suppression of spatiotemporal behavior in excitable media, a lot of methods for suppression have been proposed [2]. Most methods are classified into *nonfeedback* controls: an external force is unilaterally applied to a medium without using information of medium state. It is easily imagined that the characteristics of cardiac tissue depend on individual factors, such as body weight, age, health, and so on; thus, the electric shock must be changed for individuals. On the other hand, in recent years, several *feedback* controls, it is adaptively applied with using information of medium state, have been proposed [3, 4, 5, 6]. In general, the feedback controls essentially have the following advantage: the control performance does not degrade even for external disturbances or changes in their environments. However, there have been few efforts to show the advantage of feedback controls for excitable media.

The present report deals with a feedback suppression of Bär model [7]:

$$\left\{\begin{array}{l} \dfrac{\partial u}{\partial t} = \dfrac{1}{\varepsilon} u(1-u)\left(u - \dfrac{v+b}{a}\right) + \nabla^2 u \\ \dfrac{\partial v}{\partial t} = g(u) - \alpha v + e \end{array}\right. ,$$

where u and v are state variables. $g(u)$ is given in Ref. [7]. $\nabla^2 := \partial^2/\partial x_1^2 + \partial^2/\partial x_2^2$ denotes the Laplace operator. $x_1 \in [0, L]$ and $x_2 \in [0, L]$ are the position, where L represents the width of medium. $0 < \varepsilon \ll 1$, a, and b are the parameters. Remark that α is an uncertain parameter. The ratio of a space mean excited-area to the whole medium area L^2, that is y, can be measured in real time. The present report proposes the external impulsive force, $e = E_0$ if $t \in [t_i, t_i + \Delta t]$ or $e = 0$ otherwise, which is applied spatially uniform. E_0 and $\Delta t \ll 1$ are the amplitude and the small interval of the external force. t_i denotes the time which satisfies $y|_{t=t_i} > y_0$, $\{\mathrm{d}y/\mathrm{d}t\}_{t=t_i} = 0$, and $\left\{\mathrm{d}^2 y/\mathrm{d}t^2\right\}_{t=t_i} > 0$. We see that y is the local minimum value at time t_i, where $i \in \{1, \ldots, n\}$ represents the number of the local minimum.

Our numerical simulations show that the external impulsive force e based on the feedback control successfully suppresses traveling waves in the medium with uncertain parameter. Furthermore, we confirm that the robustness of the performance on our feedback control with respect the uncertain parameter is superior to that on nonfeedback control.

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EFFECTIVE SOURCE OF ULTRA WIDEBAND SIGNALS

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Application of ultra wideband (UWB) signals is actively investigated in communications. In particular, UWB signals are adopted in wireless personal area networks (WPANs) that are developed within the limits of IEEE 802.15.4a and 802.15.6 standards. One of the signal types that are recommended for use in UWB WPANs as an information carrier is chaotic signals. Chaotic oscillations have certain advantages which make them attractive to use in UWB applications. Among these are: ultra wide bandwidth (naturally spread spectrum), large variety of chaotic modes in oscillators and possibility of their control, relative simplicity of oscillators, self-synchronization, stability to fading in multipath environment, etc. A promising approach to UWB communications is the so called direct chaotic communication (DCC) scheme. The basic idea of DCC is that generation of chaotic carrier, its modulation and demodulation by information signal are performed in microwave band [1 - 4]. Effective sources of UWB chaotic signals are necessary for implementation of such systems. These sources must have a simple structure, form a chaotic signal in a necessary frequency band and provide uniformity of power spectral density. The main requirements to the sources are: low weight and size, reliability, low power consumption, etc.

In this report, structure of the ring UWB microwave oscillators based on three active elements and capable to generate ultrawideband microwave chaotic signal with uniform power spectral density, is proposed. Its evolution from distributed elements implementation to CMOS IC realization is demonstrated in simulation and experimentally. Dynamics of the basic oscillation modes are investigated, the fact of the chaotic generation is shown. Chaotic oscillations in such oscillator type are really excited on the basis of double-frequency oscillations mode destruction mechanism. It is shown that such oscillators can be used in different wireless communication applications as a compact device for UWB microwave chaotic signal generation with uniform power spectral density in frequency bandwidth up to 5 GHz and integrated output power reaches about 20 dBm.

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Delay independent design for chaotic synchronization in delay-coupled Bernoulli map networks

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The rich phenomena arising from coupled oscillators have been a great attention in nonlinear science. One of the most widely studied phenomena is synchronization. It is well-known that the local stability of synchronous state is equivalent to that of *time-varying* linear systems [1]. Since it is difficult to derive the analytical condition for *time-varying* linear systems to be stable, some numerical calculations are needed to analyze the local stability of synchronous state.

The interaction of coupled oscillators inevitably contains a certain time delay due to finite propagation speed of information. Therefore, the dynamics of delay-coupled oscillator networks has been extensively investigated in recent years. The local stability of the synchronous state is governed by *time-varying* linear systems with time delay. It is not easy to analyze the stability because of the following two facts: (a) The dimension of such linear systems is infinite due to the time delay; (b) The linear systems contain time-varying parameters which depend on the synchronous state.

Delay-coupled map networks, which have discrete-time dynamics, do not have fact (a). Moreover, we can numerically obtain high precision orbits without numerical integration. Thus, coupled map networks are considered as suitable models for investigation of dynamics in large-sized networks with time-delay connections. The synchronization in delay-coupled map networks have been widely investigated. However, most of previous studies do not provide analytical conditions for the synchronous state to be stable, since there still remains fact (b). For delay-coupled Bernoulli map networks, the local stability of the synchronous state can be reduced to that of *time-invariant* linear systems because such networks do not have fact (b). As a result, we can easily derive an analytical condition for the synchronous state to be stable.

This report proposes a design procedure of a coupling strength and a map parameter such that chaotic synchronization is induced in delay-coupled Bernoulli map networks. We consider a practical situation where the time-delay in connection, the number of maps, and the detailed information of network topology are not obtained. It is shown that the local stability is equivalent to that of a *time-invariant* linear system with uncertain parameter and uncertain dimension. Although it is difficult to derive the necessary and sufficient condition for such uncertain linear system to be stable, we can derive a simple sufficient stability condition by a criteria [2], which was provided in the field of control theory, for designing the strength and the parameter. Our design procedure is confirmed by some numerical simulations.

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Effective Connectivity and Cortical Information Flow under Visual Stimulation in Migraine with Aura

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ABSTRACT

The study aims to evaluate effective connectivity patterns in EEG rhythms under repetitive visual stimulation in migraine with aura patients, in terms of non linear Granger causality and Transfer Entropy. Fifteen migraine with aura (MWA) and 15 migraine without aura (MWoA) patients were evaluated interictally. All subjects were submitted to high density (65 channels) EEG during visual stimulation by black and white checkerboard gratings with two spatial frequencies (0.5 and 2.0 cpd) at 5 and 10Hz (10 and 20 reversal/s). Our results outline important pathophysiological difference between migraine phenotypes. An increased capacity in cortical connections and transfer information may subtend the perception of aura symptoms, probably favoring the progression of cortical spreading depression.

RESULT

The stimulus-related modulation of effective connectivity in alpha and beta band, evaluated by means of non linear Granger Causality and Transfer Entropy [1], was significantly different across groups: smaller values were observed in migraine without aura patients than in migraine with aura patients, under all the stimulation modalities. These differences were more evident for all the modalities of stimulation, for a larger extent of information transfer involving specially the occipital and fronto-central scalp derivations in MWA patients. The fronto-central electrodes showed the highest values of “in” and “out” transfer connections able to separate the two groups. The total amount of information transfers in both the directions for alpha and beta band, was clearly prevalent in migraine with aura patients, with respect to patients not reporting aura symptoms. Moreover, the BCT analysis showed the MWA patients to be more segregate (i.e. less incline to share information) and less integrated and efficient than the MWoA ones, having a smaller path length (i.e., a greater distance) between nodes and a greater clustering coefficient, even presenting a high-level degree with respect to the MWoA's, especially in the occipital region. On the other hand, MWA was found to have an higher resilience level, in particular in the occipital area.

DISCUSSION

A pattern of increased information flow across channels was particularly evident in regard to alpha and beta band in MWA and was able to clearly differentiate the two forms of migraine. The beta rhythm is generally associated with a state of cortical activation, and up to now few reports have described its changes under intermittent visual stimulation [23]. In this study GC and TE measured the total amount of information transfer across electrodes in any direction, which may be interpreted as a sign of activation of different interacting functional networks [24]. In particular, we found that strong causal connections were activated in migraine with aura across posterior and anterior electrodes. In the case of migraine without aura compensatory phenomena of reduced connectivity and functional networks segregation may limit the extension of cortical recruitment [25]. A facilitation of synaptic connections from the occipital to the frontal regions, may also subtend the progression of bioelectrical phenomena accompanying aura symptoms perception [4, 5]. Considering the present results, we can suppose that an increased extent of occipital cortex activation in migraine with aura, may initiate a cascade of synaptic events across brain areas, potentially responsible of progression of bioelectrical events within the cortex.

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BIFURCATIONS BY EVOLUTION OF THE ORDER PARAMETER OF CHAOS

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At the present time constructing of bifurcation diagrams for a nonlinear dynamical system can be realized by use of a certain parameter which changes the state of the system. Therefore it is impossible to construct a bifurcation diagram of a dynamical system without of using an order parameter of the dynamical system. A lot of natural phenomena can be described without of using an order parameter of the dynamical system. For example, time realizations of astronomical processes, changes of weather, earthquake magnitude, etc., doesn’t contain an order parameter. Naturally, we arise the question: is it possible to construct a bifurcation diagram without the order parameter of a dynamical system?

To solve this problem we propose the new expression for the order parameter of an evolutionary process. This option allows constructing a bifurcation diagram for a realization without knowing the equation describing a dynamical system.

We have used a new approach for the constructing of bifurcation diagrams for previously investigated models of dynamical systems such as the logistic map, Henon map, maps for oscillations described as “accumulation - bursting” and for systems with homoclinic bifurcations.

We have compared these diagrams with the previously well - known diagrams constructed via parameters of the equations for dynamical system. The main advantage of our method is a statement that we can study bifurcation phenomena via realizations only, i.e. if original equations for the description of these phenomena are unknown. We have also shown the unity of nature of homoclinic bifurcation of «gluing» type with the bifurcation with the oscillations of the "accumulation - bursting" type.

According to this method we can determine state of a system with unknown parameters. This method can be applied to analysis of different complex phenomena.

GENERAL THEORETICAL MODEL DESCRIBING COEXISTENCE OF TWO TYPES OF INTERMITTENCY IN NONLINEAR DYNAMICAL SYSTEMS

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Intermittency is a typical phenomenon in nonlinear systems. It is observed, in particular, at transition from periodic oscillations to the chaotic ones as well as near the boundaries of different types of chaotic synchronization in coupled oscillators.

There is a certain classification of intermittent behavior. In particular, intermittencies of types I-III [1], on-off intermittency [2], eyelet intermittency [3] and ring intermittency [4] are traditionally distinguished. Despite of some similarity (i.e., the existence of two different types of alternating behavior in time series), each type of intermittency possesses its own peculiarities and characteristics (first of all, these are the dependence of mean length of laminar phases on the criticality parameter and the distribution of the laminar phase lengths). The mechanisms resulting in the appearance of intermittent behavior for each type are also different.

Recently [5, 6] we have shown the possibility of the coexistence of two different types of intermittency in nonlinear dynamical systems. Such type of behavior has been called the «intermittency of intermittencies». This type of behavior of nonlinear dynamical systems consists in the fact that two different mechanisms of the turbulent phase appearance exist simultaneously in the system under study. For example, the possibility of the coexistence of ring and eyelet intermittencies in two unidirectionally coupled chaotic Rössler oscillators has been studied in [5] whereas the simultaneous presence of ring and type I intermittencies in non-autonomous Van der Pol oscillator with noise has been considered in [6].

Despite of the fact that «intermittency of intermittencies» has been actively studied recently, the general theory describing this type of behavior has not been developed so far. Therefore the development of the general theory of this type of the behavior is of the great interest since it allows to understand more deeply the mechanisms and nature of such fundamental phenomena as intermittency and chaotic synchronization.

In the present work the general theory describing the coexistence of two different types of the intermittent behavior in nonlinear dynamical systems has been proposed. In particular, the analytical dependencies describing the distributions of the laminar phase lengths for the fixed values of the control parameters of the system and the dependence of the mean length of laminar phases on the criticality parameter have been deduced. The theoretical relations have been compared with the numerical data obtained for two-dimensional map. Very good agreement of the analytical and numerical results has been shown.

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