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Reconstructions of Parameters of Radiophysical Chaotic Generator with Delayed Feedback from Short Time Series

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ABSTRACT

A method for the reconstruction of time-delayed feedback system is investigated, which is based on the detection of synchronous response of a slave time-delay system with respect to the driving from the master system under study. The structure of the driven system is similar to the structure of the studied time-delay system, but the feedback circuit is broken in the driven system. The method efficiency is tested using short and noisy data gained from an electronic chaotic oscillator with time-delayed feedback.

Time-delay systems, reconstruction, chaos, radiophysical experiment

1. INTRODUCTION

Reconstruction of real-world time-delay systems from experimental data is an important problem for optics[1], radio physics, chemistry, and for applied medicine. In application to non-living systems, the reconstruction is used, for example, for data transmission and estimation of parameters of real devices. The application of reconstruction to biological objects can enhance our fundamental understanding of living beings and benefit the medical diagnostics[2,3].

However, the problem of reconstruction of time-delay systems is rather difficult. Traditional approaches, proposed for systems without delay, are usually inapplicable even for model time-delay systems. Moreover, the experimental data are always corrupted by dynamical and measurement noises of various origins and the length of available time series is often short. These difficulties are especially severe for data of biological origins. Different restrictions imposed on data recording and high nonstationarity of living systems enforce the analysis of short time series.

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To overcome such complex problem, specialized approaches are required[4-9], which take into account a priori information about the studied system. Moreover, the methods should be adjusted to a particular system. The physical experiments can be conducted to test the method resistance to discretization and measurement noise.

In the present study, a specialized approach is used to reconstruct a hybrid chaotic time-delayed feedback oscillator. The form of delay-differential equations for the studied system is assumed to be known in advance. This knowledge is employed for constructing a slave system that is driven by the signal from the master system under investigation. The procedure of reconstruction exploits the analysis of synchronous response of the driven system with respect to the signal of the master system.

2. METHODS

The proposed method of reconstruction is oriented to the systems described by the following equation:

$$\varepsilon_0 \dot{x}(t) = -x(t) + f(x(t-\tau_0)), \qquad (1)$$

where τ_0 is the delay time, ε_0 is the parameter that characterizes the inertial properties of the system, and f is a nonlinear function.

The method is based on the detection of synchronous response of the driven system. The structure of the driven system is similar to the structure of the studied system, but the feedback circuit in the driven system is broken. The slave system $y(t)$ is driven by the signal $x(t)$ from the master system, Fig. 1. The signal $z(t) = x(t) - y(t)$ is the output of subtractor. If the parameters of the driven and studied systems are identical, then the dispersion D of the signal $z(t)$ is defined only by measurement noises and is equal to 0 in the absence of noise. If the parameter values of the driven and studied system are different, the dispersion of $z(t)$ will be close to the dispersion of the signal $x(t)$. Similar approach was implemented in chaotic system of hidden data transmission[10].

To estimate the parameters $\vec{a}$ of nonlinear function and parameters τ and ε, we conducted the minimization of the objective function $D(\tau; \varepsilon; \vec{a})$.

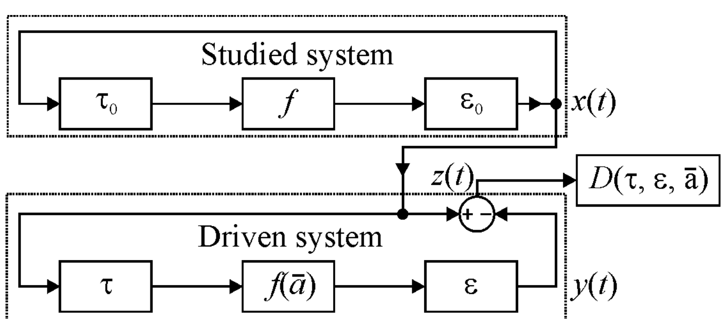

Figure 1. Block Diagram of the Method of Reconstruction.

3. Objects of investigation

We use a chaotic electronic oscillator with time-delayed feedback. A block scheme of this oscillator is shown in Fig. 2. The oscillator is implemented as a hybrid device. The delay line and nonlinear element are implemented in a digital form using 32-bit ARM-microcontroller (MC) Atmel ATSAM3X8E, while the inertial element is implemented in an analog form using a low-pass first-order RC-filter (LPF). The digital and analog elements of the scheme are connected with the help of 16-bit digital-to-analog converter (DAC) and analog-to-digit converter (ADC).

Sensitive repeating amplifiers Analog Devices AD822 were placed on input and output lines of LPF. Dynamical variable taken from output of LPF was digitalized by 16-bit ADC National Instruments PXIe-6355 with 0.1 Mega Hz sample rate and then was stored in personal computer for further reconstruction. ADC, DAC and MC processing were synchronized by interruptions of precise 32-bit timer. Using block of automatic frequency control 20 MHz quartz resonator clocked core of the MC with 84 MHz clock signal (maximal frequency for this particular MC). This setup performed one cycle of numerical calculations within $\Delta t = 10^{-5}$ s. Data on the DAC output and ADC input are also refreshed during this time frame.

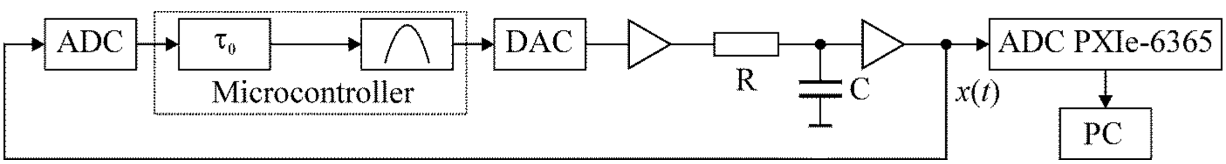

Figure 2. Block Diagram of Experimental Setup for Studying of Chaotic Time-Delay Generator with Square Nonlinearity. Repeating Amplifiers with AD822 Microchip are Shown as Triangles.

Quadratic transformation was chosen as transfer-function for nonlinear block of time-delay generator. Thus, this generator can be described as:

$$RC\dot{x}(t) = -x(t) + \lambda_0 - x^2(t-\tau_0), \tag{4}$$

where $x(t)$ - control value, $RC = \varepsilon_0$ - response time of LPF. Equation (4) can be transformed to form (1) by following changes: $\varepsilon_0 = RC$, $f((t-\tau_0)) = \lambda_0 - x^2(t-\tau_0)$. During our experiments time-delay generator had following parameters: R=5358.8 Ohm, C=46.6 nF, ε_0 =203 ms, τ_0 = 2500 ms (250 delay times), =1.74 V.

Results of reconstruction of experimental signals were compared with the results obtained from numerical solution of mathematical model of the identical time-delay generator. It was carried out to exclude the influence of discretization noises and measurement noises from analog components.

4. RESULTS

Figure 3 shows sections and power spectra of signals from experimental radiophysical setup and mathematical model described by equation (4). Calculation of standard deviation from experimental and model signals led to the values of 0.8 V and 0.81 V respectively. Therefore, approximately 1% of standard deviation of experimental signal is caused by noises of various origins.

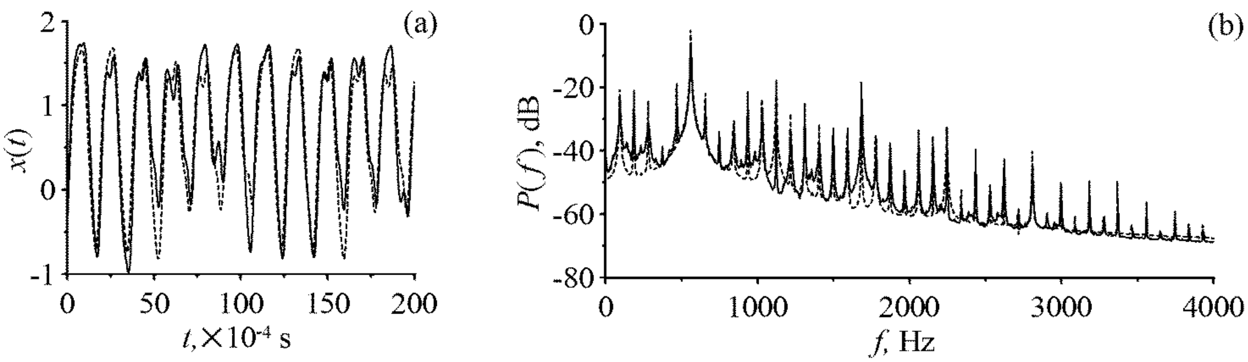

Figure 3. (a) – Time-Series and (b) – Power Spectra of Experimental Setup (Bold Line) and Model of Time-Delay Generator (dashed line).

Assuming that equation structure in a form of (4) is priori known we reconstructed the parameters of this equation from obtained chaotic time-series. Cross-sections of D(τ, ε, λ) function for each parameter, while other parameters correspond to the minimal value of D, are presented in figure 4 for both radiophysical and numerical experiments.

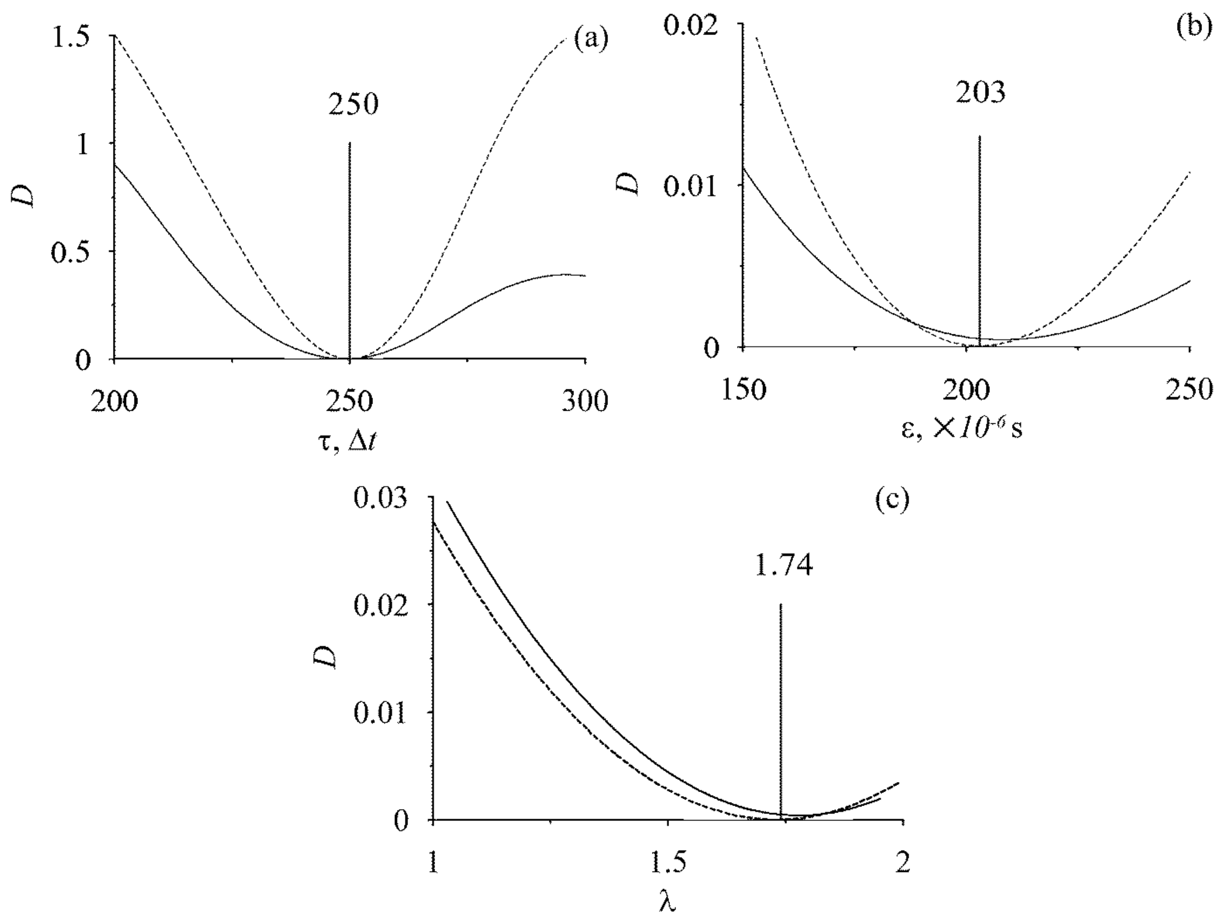

Figure 4. Cross-Sections of D(τ, ε, λ) Function for Parameters (a) - τ, (b) - ε, (c) - λ, while Other Parameters Correspond to the Minimal Value of D. The Cross-Sections were Calculated from Time Series of Radiophysical Chaotic Generator (Bold Line) and of Noiseless Model of Time-Delay Generator (Dashed Line).

With conducted procedure of reconstruction we recovered the following values of parameters from time-series of numerical model: τ^M =2500 ms, ε^M =203 ms, λ^M =1.74 V, and from experimental data: τ^E =2490 ms, ε^E =208 ms, λ^E =1.78 V. We discovered that 0.004 s long time-series (400 counts of discrete time – 1.5 delay times) are enough to recover the parameters of both experimental and numerical systems. Use of time-series of greater length had not resulted in further improvements of accuracy.

5. CONCLUSION

Study focuses on reconstruction of chaotic time- delay systems from short time-series in presence of noises of various origins. Specialized method of reconstruction was used to reconstruct the parameters of hybrid electronic delay-time generator, taking into account prior information about this system. Delay time is reconstructed precisely, inertial term is reconstructed with error less than 0.1% and tabulated nonlinear function have normalized mean-square error (divided by dispersion of experimental data) of less than <0.001 in relation to true nonlinear function. Reconstruction of hybrid chaotic delay-time generator was performed from time-series as long as 1000 samples of dynamical variable (near 1.5 delay times). Obtained results suggest that specialized methods perform precise reconstruction from significantly shorter time-series than universal methods.

6. ACKNOWLEDGMENTS

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