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Real-time deterministic chaos control by means of selected evolutionary techniques

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A B S T R A C T

This contribution introduces continuation of an investigation on deterministic spatiotemporal chaos real-time control by means of selected evolutionary techniques. Real-time-like behavior is specially defined and simulated with the spatiotemporal chaos model based on mutually nonlinearly joined n equations, so-called coupled map lattices (CML). Four evolutionary algorithms are used for chaos control here: differential evolution, self-organizing migrating algorithm, genetic algorithm and simulated annealing in a total of 12 versions. For modeling of real-time spatiotemporal chaos behavior, the so-called CML were used based on logistic equation to generate chaos. The main aim of this investigation was to show that evolutionary algorithms, under certain conditions, are capable of real-time control of deterministic chaos, when the cost function is properly defined as well as parameters of selected evolutionary algorithm. Investigation consists of four different case studies with increasing simulation complexity. For all algorithms, each simulation was repeated 100 times to show and check robustness of used methods. All data were processed and used in order to get summarizing results and graphs.

1. Introduction

Deterministic chaos, discovered by Lorenz (1963), is a fairly active area of research in the last few decades. The Lorenz system produces one of the well-known canonical chaotic attractors in a simple three-dimensional autonomous system of ordinary differential equations (Lorenz, 1963; Stewart, 2000). For discrete chaos, there is another famous chaotic system, called logistic equation (May, 1976). Logistic equation is based on a predator–prey model showing chaotic behavior. This simple model is widely used in the study of chaos, where other similar models exist (canonical logistic equation, Gilmore and Lefranc, 2002) and one-dimensional (1D) or two-dimensional (2D) coupled map lattices (CML) (Schuster, 1999). Since then, a large set of nonlinear systems that can produce chaotic behavior have been observed and analyzed. Chaotic systems thus have become a vitally important part of science and engineering in theoretical as well as practical levels of research. The most interesting and applicable notions are, for example, chaos control and chaos synchronization related to secure communication, amongst others.

Recently, the study of chaos is focused not only along the traditional trends but also on the understanding and analyzing principles, with the new intention of controlling and utilizing chaos as demonstrated in Chen and Dong (1998) and Wang and Chen (2000). The term *chaos control* was first coined by Ott et al. (1990). It represents a process in which a control law is derived and used so that the original chaotic behavior can be stabilized at a constant level of output value or an n-periodic cycle. Since the first experiment of chaos control, many control methods have been developed and some are based on the first approach (Ott et al., 1990), including pole placement (Grebogi and Lai, 1999; Zou et al., 2006) and delay feedback (Just, 1999; Just et al., 2003). Another research has been done on CML control by Deilami et al. (2007); special feedback methods for controlling spatiotemporal on–off intermittency has been used there and in Cherati and Motlagh (2007). This paper introduces a controller (based on discrete-time sliding mode and Lyapunov function) for controlling of the spatiotemporal chaos system.

Many methods were adapted for the so-called spatiotemporal chaos represented by CML. Control laws derived for CML are

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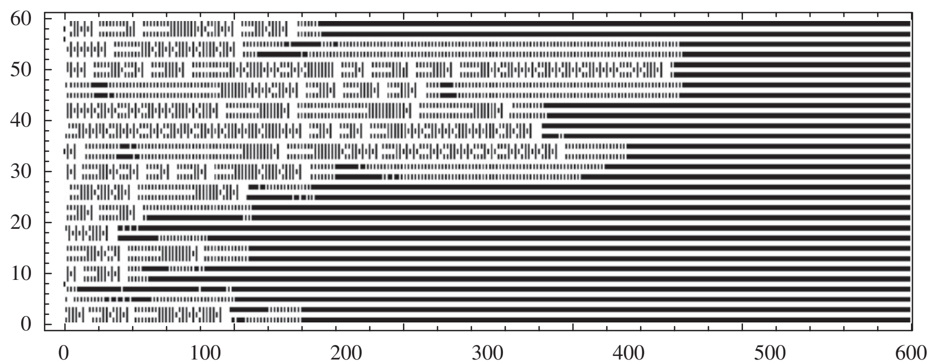

Fig. 1. 1D CML with stabilized pattern T1S2.

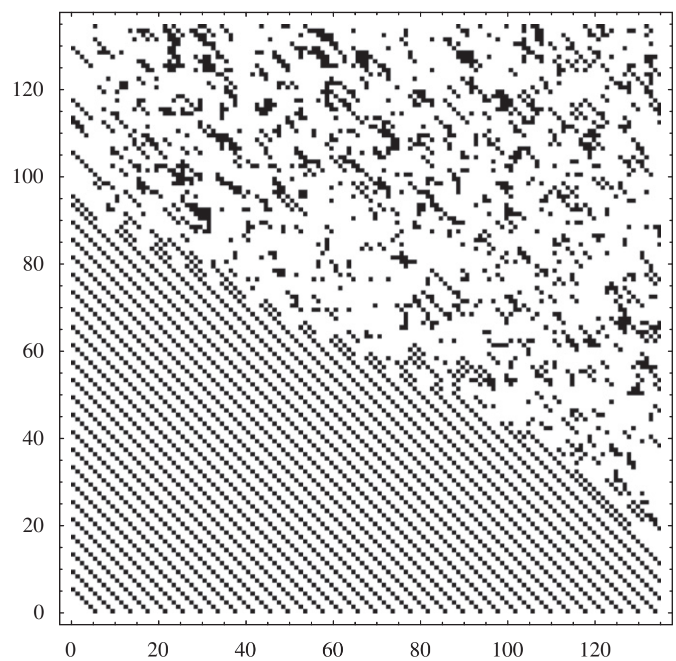

Fig. 2. 2D CML with pinning imported through the lattice on position (0,0). Resulting control pattern (left) is visible as well as spatiotemporal chaos (right).

usually based on existing system structures (Schuster, 1999), or using an external observer (Chen, 2000). The evolutionary approach for control was also successfully developed in, for example, Richter and Reinschke (2000), Richter (2002) and Zelinka (2006).

Many published methods of deterministic chaos control (DCC) were (originally developed for classic DCC) adapted for so-called spatiotemporal chaos represented by CML, given by (1). Models of this kind are based on a set of spatiotemporal (for 1D, Fig. 1) or spatial (for 2D, Fig. 2) cells that represent the appropriate state of system elements. Typical example is CML based on the so-called logistic equation (May, 1976; Hilborn, 1994; Chen, 2000), which is used to simulate the behavior of system that consists of "n" mutually joined cells—logistic Eq. (1).

$$x_{n+1}(i) = (1-\varepsilon)f(x_n(i)) + \frac{\varepsilon}{2}(f(x_n(i-1)) + f(x_n(i+1))) \tag{1}$$

The main aim of this participation is to show that evolutionary algorithms (EAs) are capable of controlling (as was also shown for temporal DCC in Richter and Reinschke (2000) and Richter (2002)) CML as a real-time process as well as deterministic methods without internal system knowledge operating with CML as with a black box. The ability of EAs to successfully work with a problem kind of black box has been proven; see for example real-time control of plasma reactor (Nolle et al., 2001, 2005; Zelinka and Nolle, 2006) or CML non-real-time control by EAs (Zelinka, 2005a, b; Zelinka et al., 2007).

This paper is organized as follows. The first part outlines the motivation of this investigation. This is followed by a brief survey of EAs that follow, along with a brief description of the idea of real-time chaos control and used EAs. Evolutionary chaos control is then studied, and finally experimental results are reported, followed by conclusion.

This participation is a continuation of previous experiments (Zelinka, 2005a, b) with such difference that the CML behavior is controlled to the more complex pattern and all simulations are designed so that real-time CML is imitated.

2. Motivation

Motivation of this investigation is quite simple. As mentioned in Introduction, EAs are capable of hard problem solving. A number of examples about EAs can be easily found. For example, Dashora et al. (2007) developed statistically robust EAs; on the contrary, Hwang et al. (2007) used EAs for fuzzy power system stabilizer that has been applied on a single-machine infinite bus system and a multi-machine power system. Another research was done by Liu et al. (2007). Parameters of permanent magnet synchronous motors has been optimized by particle swarm algorithm and experimentally validated on a servomotor. Das and Konar (2007) have used swarm intelligence for IIR filter synthesis and He and Wang (2007) used the co-evolutionary particle swarm optimization (CoPSO) approach for the design of constrained engineering problems. Especially for pressure vessel, compression spring and welded beam has been CoPSO has been used to optimize pressure vessel, compression spring and welded beam in this research.

The main question in the case of this participation was whether EAs are able to control and stabilize chaotic systems like CML and whether they are capable of controlling CML like a black box system, i.e. when the structure of the controlled system is unknown. All experiments here were designed to check this idea and confirm or cancel this idea.