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Parameter identification for Van Der Pol–Duffing oscillator by a novel artificial bee colony algorithm with differential evolution operators ☆

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ABSTRACT

This paper is concerned with the uncertain parameters' identification of Van Der Pol–Duffing oscillators (VDPD) through a non-Lyapunov way with ABC and ABCDEO respectively by converting the problem into a multiple modal non-negative functions' minimization, which is of vital significance and attracts increasing interests in various research fields. Firstly, a novel artificial bee colony (ABC) algorithm with differential evolution operators (ABCDEO) is introduced to accelerate ABC due to the slow nature of the collective intelligence of honey bee swarms, by doing differential evolution operators to the employed bees colony in a certain probability, a special region contraction rules, and swarm re-initialization strategy based on number-theory nets. Secondly, the unknown parameters of VDPD for three main physical states, the cases with noise, and a comprehensive set of twelve complex benchmark functions including a wide range of dimensions, are employed for experimental verification. Experimental results confirm that the ABCDEO is a successful method in VDPD's parameters' identification.

1. Introduction

The traditional trend of analyzing and understanding chaos has already evolved a new phase in investigation: controlling and utilizing chaos [1,2]. And estimating the unknown parameters of the chaos are of vital importance. Unfortunately, it is difficult to obtain the exact values of the time delays and the parameters for practical chaotic systems. Actually, parameters

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identification of chaotic system is the chief task to be resolved. And a series of estimation methods are proposed based on genetic algorithms (GA), chaotic ant swarm algorithms, particle swarm optimizations (PSO) and quantum PSO, etc. [3–11].

However, to the best of authors' knowledge, little work has been done through artificial bee swarm algorithms recently proposed [12–21], to identify the uncertain parameter identification of Van Der Pol–Duffing oscillators (VDPD) [22], which is of vital significance and attracts increasing interests in various research fields.

The objective of this work is to present a simple but effective estimation methods to detect uncertain parameters of VDPD. In which, the problems are resolved by ABC and ABC with differential evolution operators (ABCDEO) self-adaptively, a special region contraction rules, and swarm re-initialization strategy in a non-Lyapunov way. And the illustrative examples in three main states of VDPD are discussed respectively.

Artificial bee colony (ABC) algorithm is one of the most recently introduced swarm-based algorithms. ABC models the intelligent foraging behavior of a honeybee swarm and is proven to be a better heuristic for global numerical optimization [12–21,23–27], since Karaboga [14] studied on ABC algorithm and its applications to real world-problems in 2005.

In ABC algorithm, the artificial bee colony consists of three groups of bees: employed bees, onlookers and scouts. The first half of the colony consists of the employed artificial bees and the second half includes the onlookers. In some degree, this is similar to genetic operators in genetic algorithms. The minimal model of forage selection that lead to the emergence of collective intelligence of honey bee swarms consists of three essential components: food sources, employed foragers and unemployed foragers, and defines two leading modes of the behavior: recruitment to a nectar source and abandonment of a source [14–18,23–26,28,29].

However, this colony-based algorithm is computationally expensive due to the slow nature of the collective intelligence of honey bee swarms.

Differential evolution (DE) algorithm is a novel minimization method in evolutionary algorithms, capable of handling nondifferentiable, nonlinear and multi-modal objective functions, with few, easily chosen, control parameters [30,31]. Since seminal idea on using vector differences for perturbing the vector population, a lively discussion between Ken and Rainer and endless ruminations and computer simulations on both parts yielded many substantial improvements which make DE the versatile and robust tool it is today [30,32].

The objective of this work is to present a simple but effective way to accelerate ABC. In which differential evolution operators in probability, a special region contraction rules, and swarm re-initialization strategy are added to the employed bees colony of ABC.

The rest is organized as follows. Section 3 provides brief review for VDPD. And a proper mathematical optimization is constructed to transform the problems of identification the unknown parameters α, β, μ in VDPD oscillators into the minimization of function $g(\alpha, \beta, \mu)$. Section 3 provides brief review for ABC. In Section 4, a proper mathematics model is introduced to hybridize ABC with DE operators (ABCDEO). In Section 5, includes twelve typical simulation examples by ABCDEO to illuminate the effectiveness of results obtained. Conclusions are summarized briefly in Section 6.

2. Van Der Pol–Duffing oscillators

Normally, a dynamic system is a system that evolves in time, whose behavior changes continuously [22,33–35]. And it is mathematically described by a set of first-order autonomous ordinary differential equations.

$$\frac{d\vec{Z}(t)}{dx} = \vec{F}(\vec{Z}(t), \vec{\mu}) \tag{1}$$

The vector $\vec{Z}(t)$ represents the dynamical variables of the system (1), the vector $\vec{\mu}$ represents parameters, and the dynamical rules for the behavior of the dynamical variables is F.

As the nonautonomous system in $\Re^n$ can be transformed into an autonomous system in $\Re^{n+1}$, then F in autonomous systems is not an explicit function of t. When the vector field is affine, $\vec{F}(\vec{x}, \vec{\mu}) = A(\vec{\mu})\vec{x} + \vec{b}(\vec{\mu})$ for some constant matrix A and vector $\vec{b}$, then the dynamical system is said to be linear. Otherwise it is nonlinear. In linear dynamical systems any linear combination of solutions is also a solution [33].

Van Der Pol–Duffing oscillators are one of the most extensively studied systems in the periodically forced self-excited oscillators with numerous applications in engineering [22,33–35]. And its mathematical expression is assumed in the form of the second-order non-autonomous differential equation.

$$\frac{d^2x}{dt^2} - \mu(1 - x^2) + \alpha x + \beta x^3 = g(f, \omega, t) \tag{2}$$

where x stands for the displacement from the equilibrium position, f is the forcing strength and $\mu > 0$ is the damping parameter of the system.

$$g(f, \omega, t) = f\cos(\omega t) \tag{3}$$

represents the periodic driving function of time with period $T = 2\pi/\omega$, where ω is the angular frequency of the driving force.

The behavior of this special non-linear system is characterized by three real time-independent parameters, that are μ (the damping parameter of the system, with $\mu > 0$), α, β. Van Der Pol–Duffing oscillator equation can take three main physical