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A new fractional-order hyperchaotic system and its modified projective synchronization

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ABSTRACT

A new four-dimensional (4D) autonomous hyperchaotic system is investigated at first. It is found that the fractional-order version of the system goes through periodical status to chaos and hyperchaos while the order number q is increased. We verify the realizability of the new fractional-order hyperchaotic system via a practical electronic circuit. Furthermore, an active integral sliding mode control (ISMC) scheme is proposed to achieve the modified projective synchronization (MPS) of two different fractional-order hyperchaotic systems. The sliding mode controller of MPS is derived based on the stability theory of the fractional-order system and Lyapunov stability theorem. The presented method can guarantee the synchronization error asymptotically stable and enhance the robustness of MPS. Finally, the MPS between the fractional-order Chen hyperchaotic system and the new fractional-order hyperchaotic system is considered as an example, our simulation results demonstrate the effectiveness and robustness of the proposed method.

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1. Introduction

The theory of fractional calculus dates from 17th century, but its applications to physics, chemistry, engineering and other sciences have been rapidly grown only in the recent two decades. It has been found that in interdisciplinary fields, many systems can be described more accurately by fractional differential equations in contrast to the classic "integer" methods [1–3]. Now, fractional calculus has become a fascinating theory used to investigate the control and dynamics of fractional-order systems.

Chaos is a very interesting nonlinear phenomenon, which shows extreme sensitivity to initial conditions and has noise-like behaviors. With the research of fractional-order systems, in recent years, it has been proved that many fractional-order differential systems display chaotic behaviors, such as the fractional-order Chen system [4], the fractional-order Lü system [5], the fractional-order unified system [6], etc. Generally speaking, a hyperchaotic system is defined as a chaotic attractor with more than one positive Lyapunov exponent. It implies that, comparing with the traditional chaotic system, the hyperchaotic system has dynamical behavior with higher unpredictability and randomness. Thus, the hyperchaos may be more useful in some fields such as chaos communication, encryption etc. Therefore, the topic about the theoretical design and circuitry realization of various fractional-order hyperchaotic systems has recently become a hotspot in the nonlinear science [7–10].

Inspired by the above discussions, in this paper, we proposed at first a new 4D hyperchaotic system based on the 3D integral-order Liu system. Numerical and analytical studies are carried out on its basic dynamical properties, such as equilibrium point, Lyapunov exponents and hyperchaotic dynamical behaviors. This system shows complex hyperchaotic behaviors over a wide range of system parameters. And then the fractional-order version of the

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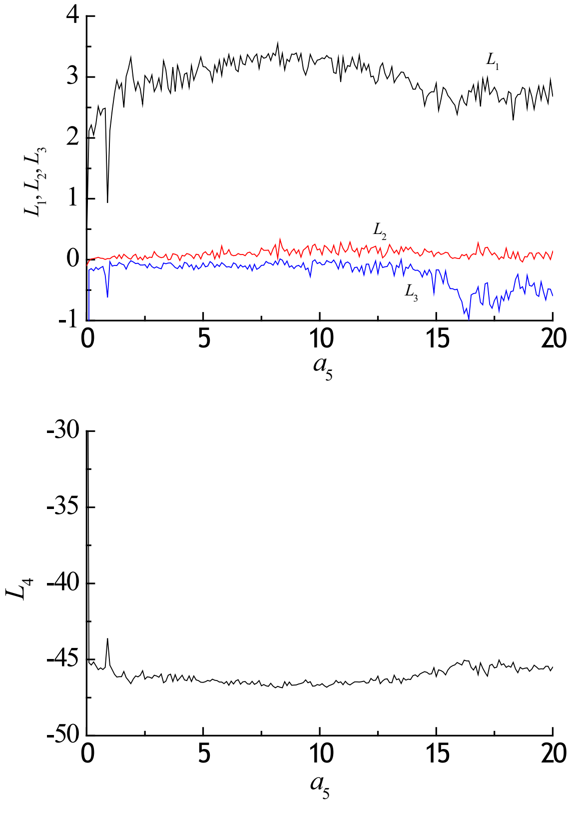

Fig. 1. Lyapunov exponents versus parameter a_5 ($a_1 = 25$, $a_2 = 60$, $a_3 = 40$, $a_4 = 4$).

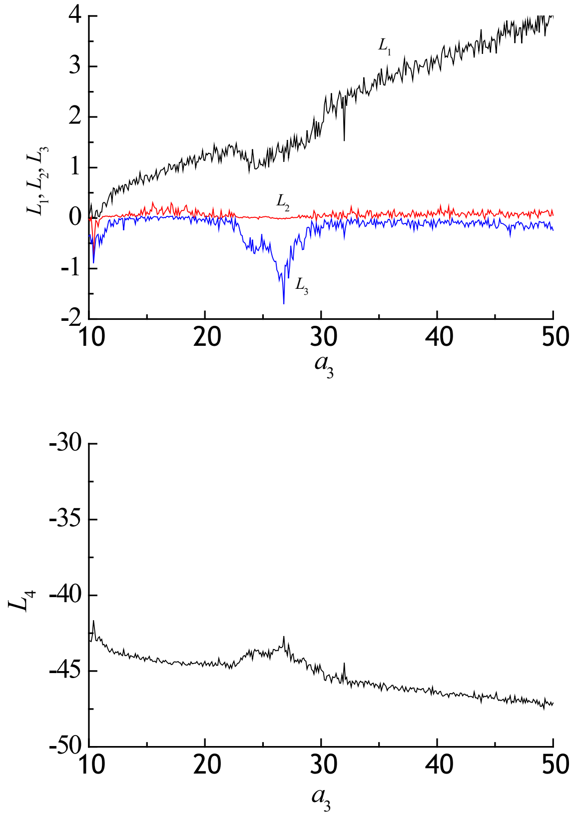

Fig. 2. Lyapunov exponents versus parameter a_3 ($a_1 = 25$, $a_2 = 60$, $a_4 = 4$, $a_5 = 5$).

system is investigated, we found that the fractional-order system goes through periodical status to chaos and hyperchaos while the order number q is increased. Especially, it is proved that the fractional-order system with $q = 0.95$ shows hyperchaos by calculating out two positive Lyapunov exponents. Furthermore, we design an electronic circuit to implement this fractional-order hyperchaotic system. The practical circuit experiment results show good agreement with the numerical simulation. Therefore, the proposed fractional-order hyperchaotic system may be used as a signal generator to enhance the security of chaos communication.

On the other hand, chaos synchronization has significant application prospects in many engineering fields, such as chemistry, biology, signal processing and secure communication. In the past few decades, many different types of chaos synchronization have been studied, such as complete synchronization [11], phase synchronization [12], lag synchronization [13], generalized synchronization [14], projective synchronization [15], and so on.

Among all the types of chaos synchronization, projective synchronization with proportional feature between the drive system and the response system, first reported by Mainieri and Rehacek in 1999 [15], has aroused more interest because the proportional feature can be used to extend binary digital to M-nary digital communication for achieving faster secure communication [16–18]. Ref. [19] investigated a new synchronization scheme called modified projective synchronization (MPS), in which the states of the drive system and response system are synchronized up to a constant scaling matrix. Park [20] studied the adaptive control method to realize the MPS of 4D chaotic system with uncertain parameters. Cai et al. [21] applied the active sliding mode control technique to achieve MPS between two chaotic systems. Nevertheless, most results about the MPS mentioned above and other existing synchronization methods focus on integral-order chaotic systems.

However, the synchronization problem of the fractional-order chaotic systems could not be compared with that of integral-order cases due to the complexity of fractional-order systems, it becomes a more interesting and challenging topic. In the past few years, the synchronization of the fractional-order chaotic system has attracted increasing attention due to its great prospects in secure communication and control processing. In Ref. [22], Shao presented a scheme to obtain the projective synchronization of the fractional-order chaotic Rössler system. A lag projective synchronization scheme for fractional-order chaotic (hyperchaotic) systems is proposed in [17]. In [8], based on the stable theorem of fractional-order system, Wu et al. studied generalized projective synchronization of the fractional-order Chen hyperchaotic system. More recently, Ref. [23] discussed the MPS of two uncertain fractional-order hyperchaotic systems.

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