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ORIGINAL PAPER

Qualitative analysis of a novel 4D hyperchaotic system and its chaos synchronization via active, adaptive, and sliding mode control

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Abstract: This study introduces a brand-new, four-dimensional hyperchaotic system and provides a full analysis of its dynamical characteristics. Time series, phase portraits, Poincaré maps, bifurcation diagrams, estimating the Lyapunov exponents, and determining the Kaplan–Yorke dimension are all used to examine the system. Additionally, the system's equilibrium points are located and their stability is explored. Through the use of active, adaptive, and sliding-mode control approaches, we have also synchronized the newly introduced system. The Lyapunov stability theory and Vaidyanathan's theorem are the foundations upon which the controllers are built to guarantee synchronization between the systems. Finally, MATLAB-based numerical simulations are used to verify the theoretical findings.

Keywords: Chaotic system; Chaos synchronization; Active control; Adaptive control; Sliding mode control

Mathematics Subject Classification: 93C10; 93D05; 93C35; 34D06; 34H10

1. Introduction

The complicated behavior of nonlinear deterministic dynamical systems that exhibit substantial starting condition dependence is the subject of the mathematical field known as chaos theory. Chaos theory investigates the qualitative and numerical analyses of such systems, to be more specific. Non-periodic behavior, having at least one positive Lyapunov exponent, and the total of all the Lyapunov exponents being negative are some of the distinguishing characteristics of chaos.

At present, chaos theory stands as an interdisciplinary field [1], finding extensive applications across diverse domains such as physics [2], chemistry [3], ecology [4], economics [5], biology [6], neural systems [7], cryptography [8], machine learning [9], and more. One captivating aspect is chaos control, aiming to stabilize chaotic systems through subtle perturbations, rendering their intricate behavior more predictable and advantageous [10]. The rationale behind utilizing small-scale perturbations is to refrain from making substantial alterations to the system's natural dynamics. Following the influential work by Pecora and Carroll [11], numerous synchronization techniques have been applied to various chaotic systems to achieve stability. These methods encompass identical synchronization [12], hybrid synchronization [13], lag synchronization [14], phase and anti-phase synchronization [15], projective synchronization [16], compound synchronization [17], hybrid projective synchronization [18], hybrid function projective synchronization [19], among others [22–24]. Furthermore, diverse control schemes like active control [22], adaptive control [20], backstepping [21], and sliding mode control [20] have been successfully implemented to achieve synchronization for these systems.

Considerations of higher-dimensional chaotic systems have sparked interest for their potential wide-ranging and profound applications in secure communications [25]. The inclusion of more than one positive Lyapunov exponent [26] in such systems enhances their suitability and reliability for secure communication, as it introduces greater complexity and comprehensive security to the transmitted signal. Hyper-chaotic systems [27], characterized by possessing more than two positive Lyapunov exponents, exhibit instability in multiple directions. These unique properties grant hyper-chaotic systems robust resistance to

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