

Review

# Complex Dynamics and Intelligent Control: Advances, Challenges, and Applications in Mining and Industrial Processes

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**Abstract:** Complex dynamics and nonlinear systems play a critical role in industrial processes, where complex interactions, high uncertainty, and external disturbances can significantly impact efficiency, stability, and safety. In sectors such as mining, manufacturing, and energy networks, even small perturbations can lead to unexpected system behaviors, operational inefficiencies, or cascading failures. Understanding and controlling these dynamics is essential for developing robust, adaptive, and resilient industrial systems. This study conducts a systematic literature review covering 2015–2025 in Scopus and Web of Science, initially retrieving 2628 (Scopus) and 343 (WoS) articles. After automated filtering (Python) and applying inclusion/exclusion criteria, a refined dataset of 2900 references was obtained, from which 89 highly relevant studies were selected. The literature was categorized into six key areas: (i) heat transfer with magnetized fluids, (ii) nonlinear control, (iii) big-data-driven optimization, (iv) energy transition via SOEC, (v) fault detection in control valves, and (vi) stochastic modeling with semi-Markov switching. Findings highlight the convergence of robust control, machine learning, IoT, and Industry 4.0 methodologies in tackling industrial challenges. Cybersecurity and sustainability also emerge as critical factors in developing resilient models, alongside barriers such as limited data availability, platform heterogeneity, and interoperability gaps. Future research should integrate multi-scale analysis, deterministic chaos, and deep learning to enhance the adaptability, security, and efficiency of industrial operations in high-complexity environments.

**Keywords:** chaotic dynamics; robust control; industrial cybersecurity; Mining 4.0; magnetohydrodynamics; machine learning; energy transition; stochastic modeling

**MSC:** 93A30; 93C10



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## 1. Introduction

Modern industry is characterized by increasing complexity in its processes, involving highly nonlinear phenomena, dynamic interactions across multiple scales, and significant sensitivity to external perturbations [1,2]. This complexity is particularly critical in areas such as heat and energy management, fluid transport, and machinery automation. However, it becomes even more relevant in the mining industry, where geological variability and stringent safety and performance requirements demand robust and scalable control methodologies [3,4]. In this context, the study of nonlinear systems and highly sensitive behaviors, such as deterministic chaos, has become fundamental for anticipating and controlling potentially unstable dynamics [5,6].

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