

## SPECIAL ISSUE ON LEARNING-BASED INTELLIGENT IDENTIFICATION AND CONTROL OF COMPLEX SYSTEMS

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**1. Introduction.** Modern industrial and energy systems are evolving into networks of unprecedented scale and sophistication, characterized by intrinsic nonlinearity, uncertainty, and intricate component interactions. The traditional engineering paradigm, which relies heavily on first-principle modeling and rule-based control, is increasingly challenged by these complexities, often leading to designs that are overly conservative, non-adaptive, or fragile to unmodeled dynamics and faults. This fundamental limitation has catalyzed a profound paradigm shift towards learning-based intelligent systems.

Special issue on Learning-Based Intelligent Identification and Control of Complex Systems is dedicated to exploring this frontier. It seeks to illuminate how the integration of advanced machine learning, data-driven identification, and adaptive control theory is not merely augmenting but fundamentally redefining our approach to complex system engineering. The core objective is to move beyond rigid models towards systems capable of autonomous perception, reasoning about uncertainty, and resilient self-optimization. The five research articles featured herein represent a curated snapshot of this ongoing revolution. They were selected through a rigorous peer-review process from a competitive pool of submissions, each contributing a unique and significant piece to the broader puzzle of intelligent system design.

**2. Overview of Contributions.** The contributions in this issue can be thematically synthesized into three interconnected pillars of advancement: 1) Advancing safety and fault resilience in cyber-physical systems, 2) Mastering complexity in large-scale networked system optimization, and 3) Foundational frameworks for adaptive and robust control. Together, they span the critical spectrum from safeguarding existing systems to optimizing their performance and, ultimately, providing the theoretical bedrock for next-generation adaptive controllers.

**2.1. Advancing safety and fault resilience in cyber-physical systems.** The first pillar addresses the non-negotiable imperative of safety in autonomous and semi-autonomous systems. Ye et al. tackle this challenge head-on in the context of next-generation

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transportation. It transcends conventional single-point failure analysis by systematically modeling *126 specific failure cases* in an Electro-Mechanical Brake system. Its key intellectual contribution lies in designing a heterogeneous fault-tolerant architecture that dynamically re-allocates control authority among in-wheel motors, healthy brakes, and active steering. This work exemplifies *control-oriented intelligent identification* by using system topology knowledge to “identify” redundant actuation pathways, enabling graceful degradation rather than catastrophic failure, as validated in high-fidelity progressive failure simulations.

Complementing this, Li and Fan advance the fault diagnosis and safety prediction aspects of system. Its primary contribution is the development of a coupled tribo-dynamic model that unifies elasto-hydrodynamic lubrication physics with gear lateral-torsional dynamics under crack propagation. This work provides a critical insight: RMS and kurtosis values exhibit heightened sensitivity to crack growth *when lubrication effects are explicitly modeled*. This establishes a more rigorous, physics-informed basis for *machine learning for fault detection and diagnosis*, moving beyond purely data-driven approaches to hybrid models where learning is guided by deep physical understanding.

**2.2. Mastering complexity in large-scale networked system optimization.** The second pillar confronts the “curse of dimensionality” in optimizing vast, interconnected systems like smart grids. Wang et al. present a holistic framework for demand-side management. Its sophistication is multi-fold. It integrates a dynamic, spatially-aware carbon emission factor, transforming a cost optimization problem into a true multi-objective sustainability challenge. It incorporates *user behavior modeling* as a soft constraint, bridging the gap between engineering control and human-in-the-loop systems. Technically, its clustering-based aggregation achieves a 97.58% reduction in computational complexity, a necessary enabler for real-world scalability. The use of the MTCMO algorithm represents a direct application of *learning-oriented approaches* to navigate complex, non-convex trade-off surfaces between comfort, cost, and carbon.

Tang et al. provide the essential data-driven infrastructure for such optimization. Its core innovation is the architectural synthesis of a Transformer encoder for capturing long-term temporal dependencies in grid operation and a CNN for extracting spatial topological features across the power network. The attention pooling mechanism acts as an adaptive feature selector, enhancing model robustness under dynamic grid conditions. This work is a premier example of *soft sensor development*, creating a high-fidelity, real-time virtual sensor for the critical but non-measurable variable of carbon flow, thereby enabling the data-accurate optimizations demonstrated in the previous paper.

**2.3. Pioneering foundational frameworks for adaptive and robust control.** The third pillar addresses the theoretical underpinnings required to ensure the stability and robustness of learning-enabled systems operating in uncertain environments. Lun et al. make a significant theoretical contribution by extending adaptive control to a broader class of systems. It considers nonlinear functions with polynomial growth constraints, a more general and challenging class than the commonly assumed Lipschitz condition. Its major innovation is the synthesis of an event-triggered mechanism with an adaptive intermittent controller. This framework guarantees global uniform ultimate boundedness while dramatically reducing communication and computation loads by updating control signals only when necessary. This work provides a formal, stable control architecture that can serve as a theoretical wrapper for data-driven learning modules, ensuring that the quest for adaptability does not compromise closed-loop stability.

Collectively, these five articles form a coherent intellectual arc. They progress from ensuring the survival and reliability of systems under fault to optimizing their efficiency and

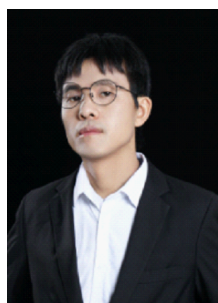
sustainability at scale, all while being guided by new theoretical principles that guarantee robust operation. A cross-cutting theme is the hybridization of models: fusing physics with key operational data, combining discrete-event and continuous control strategies, and integrating human behavior with automated algorithms.

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### Author Biography



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