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Editorial

Innovative Techniques for Safety, Reliability, and Security in Control Systems

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Control systems have become a critical component in the advancement of many engineering and science fields. With the increasing demand for safety and reliability, fault diagnosis (FD) and fault-tolerant control (FTC) systems have been developed and play a paramount role in safety-critical systems. These systems are utilized in various fields, such as water distribution networks, unmanned aerial vehicles (UAVs), aircraft, spacecraft, chemical and biochemical plants, and nuclear power plants, where even minor faults can lead to catastrophic consequences.

FD is of primary importance, as it enables online monitoring processes and facilitates the implementation of active FTC systems. In active FTC systems, the FD module determines which component exhibits abnormal behavior and feeds this information to the controller, which then redistributes or adapts the control law to maintain stability while controlling the system's performance degradation. For instance, if a UAV with faulty actuators is considered, the FTC system would redistribute the motors' thrust and torque to avoid collisions that could result in economic losses, harm to people, or loss of human life.

Recently, the scientific community has become more interested in the increasing complexity of modern control systems and has started researching systems with specific structures, such as multi-agent systems (MASs), networked control systems (NCSs), and cyber–physical systems (CPSs). These systems consider the interactions between different agents and the presence of discrete information processing and communication channels. Modern MASs, NCSs, and CPSs have transformed numerous areas and sectors, increasing overall efficiency and performance. However, they have also introduced the risk of faults due to non-reliable communication channels, non-neglectable time delays, and cyber attacks. These malicious actions, motivated by terrorism, criminality, or cyber warfare, exploit the system's vulnerabilities and result in some form of damage.

Therefore, there is a growing interest in developing new techniques or adapting existing fault diagnosis and fault-tolerant methods to secure the aforementioned systems. Control theory is continuously evolving, producing new theoretical results that can be exploited in innovative fault diagnosis and fault-tolerant control techniques.

We are excited to introduce the Special Issue that presents recent advances in developing and applying innovative safety, reliability, and security techniques in control systems. It comprises 13 high-quality papers divided into 3 literature reviews and 10 research articles. They are summarized in the following.

The first paper by Solís et al. [1] offer an extensive review of fault diagnosis in the stators of brushless direct current motors. Given their extensive range of applications, these motors are often required to operate at their limit, provoking faults, such as turn-to-turn short circuits, coil-to-coil short circuits, phase-to-phase short circuits, and phase open circuits, among others. The review covers signal processing, model-based, and data-based methods.

Li et al. [2] deeply analyze, in their review, the research status and developments in hydraulic synchronous control systems that are widely used in various industrial fields. It gives an introduction to the research significance, control theory, and methods used in these systems and classifies the synchronization control systems. The equivalent, master–slave and cross-coupling control modes and their different related control algorithms are studied thoroughly. Finally, the paper presents some trends in this research field.

Hua et al. [3] present a review about automobile break-by-wire (BBW) control technology, an important safeguard mechanism in active automobile safety. The article summarizes the BBW development history, its structure, classification, and operating principles. The most important control strategies are analyzed and it also presents this technology's research status and trends taking the electromechanical brake in the braking system as an example to discuss the current challenges and the way forward.

Son and Du [4] consider a general system model where independent random variables replace the parameters with arbitrary probability distributions to quantify uncertainties. Each random variable is approximated by a polynomial depending on a Gaussian variable. The authors apply the generalized dimension reduction method, where the integrand is decomposed into a sum of functions depending on lower-dimensional spaces. The method is applied to the reliability analysis of mechanical systems.

Borja et al. [5] present a fault detection and isolation method based on non-linear sliding mode observers for a wind turbine mathematical model. Faults on the pitch and drive train systems are considered since these subsystems are prone of faults in these systems due to the operating conditions. The method is based on designing independent observers sensitive to one fault. Subsequently, the observers are arranged in a bank to isolate the failure by binary logic. The tests involve practical considerations, such as disturbance, uncertainty, and measurement noise.

Bermúdez et al. [6] propose a predictive control strategy for pressure management and reduction in leakages in water distribution networks. The control algorithm considers a pressure reduction valve (PRV) for regulating the pressure in the water distribution system. The control scheme proposes a strategy to manage the PRV's high non-linearity and considers the demand profile throughout the day and the leaks that occur in the pipeline. An Extended Kalman Filter estimates the leak's magnitude and location and, with the aid of a rule-based set point manager, reduces the fluid loss in the event of a leak.

Miloŝević et al. [7] demonstrate that continuous monitoring and recording of the data of the pumping stations operation processes (electrical parameters, such as electrical power, pressure or flow in the pipelines, water levels in the tanks, changes in various discrete states, etc.) represent a significant resource that can be used to develop various hybrid models using the appropriate data-driven techniques. The obtained models are used for diagnosis and tolerant control of the irregular operation modes, as well as the fault-tolerant control in water supply systems.

Shi et al. [8] study the application of the Cobb–Douglas production function on optimizing safety inputs to reduce accident losses of a coal mine enterprise. The entropy weight method and the analytical hierarchy process determined each safety input indicator's weight order. The Cobb–Douglas production function was used to calculate the accident loss function of the safety input structure, and the accident loss function was obtained by multiple regression analysis. The optimal configuration of safety inputs was obtained by fitting the accident loss function. Finally, the optimal loss and mean squared error of the corresponding functions of the two safety input structures were compared.

Luo et al. [9] conduct an in-depth analysis of the failure modes of intelligent ships to optimize their design and ensure regular and safe navigation. In particular, the fixed-weight Failure Mode Effects and Criticality Analysis (FMECA) is combined with the decision-making trial and evaluation laboratory method to analyze intelligent ship positioning systems' failure modes and effects. This combined method overcomes the traditional FMECA methods to differentiate between severity, incidence, and detection rates. It allows the correlation of failure causes to be analyzed, bringing the results closer to reality.

González-Rodríguez et al. [10] compare two control techniques, computational torque control and sliding mode control, when applied to a PUMA robotic arm with six degrees of freedom. Both control algorithms cope with the non-linear behavior of the robotic arm, parameter uncertainties, and perturbations. In order to validate the controllers experimentally, the authors developed a hardware interphase based on a pic microcontroller that interacts with the control algorithms programmed in Matlab.

Gómez-Coronel et al. [11] propose a two-step algorithm to calibrate the parameters of a chlorine decay model in water distribution systems (WDS) based on genetic algorithms (GA). In the first step, the GA employs historical chlorine concentration measurements at some nodes to estimate the unknown values of the bulk and wall reaction coefficients. Once the parameters have been estimated, in the second step, the decay model is used to predict the chlorine decay concentration in for each node of the WDS for any concentration input at the pumping station. Finally, a second GA-based algorithm is implemented to obtain the minimal chlorine concentration needed at the input to ensure that every node in the system meets the official normativity requirements for free chlorine in a WDS.

Borja-Jaimes et al. [12] tackle the issue of fault detection and isolation in actuators for the pitch and drive train systems of a wind turbine benchmark. The method uses a bank of sliding-mode observers that analyzes the non-linear output error injection signal required for keeping the observer in a sliding motion.

Ríos-Ruiz et al. [13] focus on developing a versatile functional observer for Takagi–Sugeno descriptor systems. A novel structure is proposed for estimating linear functions of the states in non-linear descriptor systems represented in Takagi–Sugeno descriptor form. Its distinctive feature lies in the extra flexibility in the observer design, thereby enabling enhanced estimation performance in the presence of parametric uncertainties. The designed approach is applied to a non-linear model of a single-link robotic arm with a flexible link to demonstrate its effectiveness.

The articles featured in this Special Issue are a testament to the rapid growth and exciting potential of a particular field in engineering. With its applications expanding across various domains, pursuing work in this area demands proficiency in control engineering, systems design, numerical analysis, mathematics, and process engineering, among other areas. We believe that this Special Issue will help bridge these communities and highlight the benefits of collaboration across interdisciplinary domains.

We extend our heartfelt appreciation to the enthusiastic authors, reviewers, and editorial staff who contributed to making this Special Issue possible. Their passion and expertise have enabled us to showcase the latest advancements in this field and inspire further innovation in the future.

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