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Editorial

Editorial for Special Issue: Advanced Fault Diagnosis and Fault-Tolerant Control Technology of Spacecraft

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In order to complete the various tasks in advanced space missions, such as communication, navigation, and remote sensing, single complicated spacecraft and many distributed spacecraft systems have been launched into orbit. Due to the extremely harsh outer space environment, with various categories of hazardous radiation, huge temperature variations and the aging of components to a certain extent, there may be various malfunctions/failures in components or subsystems of the spacecraft. To improve the reliability, safety, and maintainability of spacecraft systems, fault diagnosis and fault-tolerant control (FTC) for spacecraft systems subject to space disturbance and internal physical constraints have become interesting research topics in recent years. Therefore, alongside recent developments in various learning algorithms, advanced observer design, intelligent control, etc., the application of advanced fault diagnosis and FTC techniques to single complicated spacecrafts or distributed spacecraft systems (spacecraft formation flying system, spacecraft cluster, etc.) will be extensively investigated in this Special Issue.

This Special Issue aims to highlight the state-of-the-art techniques that are used for advanced fault diagnosis and the fault-tolerant control technology of spacecraft, especially for intelligent fault diagnosis algorithm development and sliding mode fault-tolerant control. This Special Issue received 20 manuscripts, 15 of which have been accepted, and 5 of which were rejected by the peer-review process.

In [1], to perform indicator selection and verification for the on-orbit fault reconstruction of a giant satellite swarm, a hybrid multi-objective fault reconstruction algorithm is proposed and then verified by Monte Carlo analysis. The simulation results not only show the algorithm's validity but also reveal the relationship between the number of satellite faults and the health of the satellite swarm. From this, the maximum number of faulty satellites allowed in the giant satellite swarm is calculated, which is significant for assessing the swarm's health.

In the work [2], free-floating flexible-joint space-manipulator dynamic modeling is studied, and a state-observer-based robust backstepping fault-tolerant control is proposed for the system joint actuator failure. For the slow subsystem, a state observer-based robust backstepping fault-tolerant controller is designed to eliminate the angle error, compensate for the uncertain parameter and the external disturbance, and achieve joint-trajectory asymptotic tracking. The use of a speed filter makes it inappropriate to measure and provide feedback about the system's velocity signals, so the controller is simpler and more precise.

In [3], the TWR characteristics and stress distribution characteristics of a high-speed bevel gear in an aero-engine are analyzed in detail by means of experiments and simula-

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tions. Based on the acoustic waveguide system and dynamic stress test system, the TWR fatigue failure monitoring experiment of the central drive bevel gear in an aero-engine is carried out, and the TWR frequency, dangerous speed, dynamic stress and fatigue fracture characteristics of a driven bevel gear are obtained. Based on the transient dynamic analysis method and Hertz contact theory, the stress distribution characteristics of the driven bevel gear, which cannot be obtained in the test under the condition of TWR, are analyzed. The influence of the changes in the working temperature and the thickness of the spoke on the TWR characteristics and the stress distribution characteristics are discussed.

In [4], the fault-tolerant control problem of hypersonic vehicles (HSVs) in the presence of unexpected centroid migration, actuator failure, and external interference is studied in depth. To account for the effect of unexpected centroid shifts, a sliding-mode observer and an adaptive estimator are designed to obtain disturbance information useful for subsequent FTC controller designs. Later, an innovative adaptive FTC scheme is suggested by employing the observer in conjunction with a specific adaptive controller consisting of a sixth-order dynamic compensator, which can guarantee the achievement of the control objective without resorting to the exact knowledge of the inertial matrix.

In [5], a neural network algorithm based on the combination of Labeling Neural Network and Relevant Long Short-Term Memory Neural Network is proposed. This is a semi-supervised exception detection algorithm that can be readily extended with business logic exception types. The self-learning performance of this multi-network is better adapted to the big data anomaly detection scenario, which further improves the efficiency and accuracy of network data anomaly detection and considers business scenario-based anomaly data detection.

In [6], a new method for fault diagnosability research based on information geometry is proposed. The problem of the diagnosability evaluation of dynamic system faults is transformed into a distance calculation problem on a manifold. The Fisher information distance is used to realize a quantitative judgment, and a quantitative evaluation index of the fault diagnosability of a satellite attitude determination system is designed.

The work [7] presents a novel predefined-time nonsingular tracking control system for a vertical-takeoff horizontal-landing (VTHL) reusable launch vehicle (RLV) in the face of parameter uncertainties, model couplings, and external disturbances. Firstly, this paper proposes a novel predefined-time prescribed performance function (PTPPF) with desired steady-state and transient performance. The convergence time of PTPPF from the transient state to the steady state can be flexibly adjusted by changing one parameter.

In [8], a fault diagnosis method based on fusion convolutional neural networks (FCNNs) is proposed for an aircraft electro hydrostatic actuator (EHA). The FCNN model optimized by MSPSO achieves an accuracy of 96.86% for identifying typical faults of the aircraft EHA, respectively, higher than the 1DCNN and the 2DCNN by about 16.5% and 5.7%.

The work [9] proposes the new multi-task learning-based time series anomaly detection (MTAD) method, which captures the spatial–temporal correlation of the data to learn the generalized normal patterns and hence facilitates anomaly detection.

In [10], to solve the problems of the existing real-time health assessments of microsatellite swarms, such as the difficulty of selecting a multisource and assessment calculation normalization, this paper proposes a real-time health assessment method applicable to mission-oriented swarms. The method divides the microsatellite swarm into three levels: a single satellite, intersatellite communication link, and swarm effectiveness, which establish a multilevel index system by adopting the reliability evaluation based on random failure and failure by loss; this is a health evaluation based on natural connectivity, and a real-time dynamic analysis based on swarm topology.

The work [11] investigated the adaptive fault-tolerant control (FTC) for a flexible variable structure spacecraft in the presence of external disturbance, multiple actuator faults, and saturation. The attitude system model of a variable structure spacecraft and actuator fault model are first given. A sliding-mode-based fault detection observer and a radial basis function-based fault estimation observer were designed to detect the time of actuator fault occurrence and estimate the amplitude of an unknown fault, respectively.

In [12], a variable structure PID controller with a good convergence rate and robustness for satellite attitude is proposed. In order to improve the system convergence rate, the variable structure for the proportional and differential term was designed, and an angular velocity curve with a better convergence rate was achieved by this variable structure. In addition, an integral partitioning algorithm was designed, and the system robustness to disturbance torque was improved; meanwhile, the negative effect of the integral term was avoided during the converging process.

The work [13] investigates the issues of an iterative learning algorithm-based robust thruster fault reconstruction and reconfigurable fault-tolerant control for spacecraft formation flying systems subject to space perturbations. Motivated by sliding mode methodology, a novel iterative learning observer (ILO) was developed to robustly reconstruct the thruster faults. Based on the fault signals obtained from the ILO, a learning output–feedback fault-tolerant control (LOF^2TC) approach was explored such that the closed-loop spacecraft formation configuration was accurately maintained in the presence of space perturbations and thruster faults.

In [14], to discover the complex interaction between spacecraft telemetry parameters and improve the efficiency and accuracy of anomaly detection, the authors propose an anomaly detection framework based on parametric causality and Double-Criteria Drift Streaming Peaks Over Threshold (DCDSPOT). Normalized Effective Transfer Entropy (NETE) is proposed to reduce the error and noise caused by the nonstationarity of the data in the calculation of transfer entropy, and then apply NETE to improve the Multivariate Effective Source Selection (MESS) causal inference algorithm to infer parametric causality.

In [15], a novel fault-tolerant control (FTC) scheme for a category of cascade nonlinear systems with mismatched uncertainties and unknown actuator faults was studied. The robust adaptive dynamic programming (RADP) is used to design an optimal sliding surface off-line. Subsequently, a simple sliding-mode control (SMC) with adaptive fault compensation is developed to guarantee reachability of the sliding mode.

Conclusions

This Special Issue focuses on advanced fault diagnosis and the fault-tolerant control technology of spacecraft. This Special Issue highlights 15 articles. In addition to fault reconstruction and fault-tolerant control for spacecraft, the research objects include fault-tolerant control for free-floating flexible-joint space manipulator, hypersonic vehicle, and a vertical-takeoff horizontal-landing (VTHL) reusable launch vehicle. Regarding the algorithm design, the development of traditional control algorithms were studied: robust backstepping, sliding mode algorithms, etc. Additionally, artificial intelligence algorithms were studied: labeling neural network and relevant long short-term memory neural network, fusion convolutional neural networks, etc. Therefore, combined with artificial intelligence algorithms, spacecraft fault diagnosis and fault-tolerant control will be a very interesting research trend in the future.

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Conflicts of Interest: The authors declare no conflict of interest.

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