# EDITORIAL

The focus of this special issue is to report on some recent developments in the advanced control and estimation fields focussing on aerial robotics, especially those that successfully consider theoretical open problems, as well as efficient implementations in practical applications.

The different methodological approaches and topics of study within this special issue demonstrate their capabilities of rejecting disturbances in complex environments, estimating the vehicle's physical parameters or states in the uncertain environment, showing robustness against inherent nonlinearities and modelling uncertainties, and maintaining an acceptable level of robust stability in harsh conditions or even in the face of faults/failures. Fifteen papers are included in this special issue.

Wang, Shen, Li, Zhang, and Gao [1] propose an adaptive sliding mode fault tolerant control (FTC) strategy for a quadrotor unmanned aerial vehicle (UAV) in the face of actuator faults and model uncertainties. In this strategy, the sliding mode reaching law, which measures the distance between the sliding variable and the designated boundary layer, was constructed to suppress chattering, whilst preserving system tracking performance. Furthermore, an adaptation scheme is developed to prevent overestimation of adaptive parameters during the process of fault compensation. To validate the effectiveness and superiority of the proposed control strategy, a comparative study was conducted via simulation.

Zhao, Ding, Jiang, Jiang and Xie [2] consider the FTC problem for a class of quadrotors with variable mass and actuator faults. In this article, the variable mass and actuator fault are both estimated using adaptive fault observers. Using the knowledge of the estimated variable mass, a non-singular terminal sliding mode controller is created to ensure satisfactory trajectory tacking performance. Also, by utilizing the information of the actuator fault estimates, an integral sliding mode controller is designed to track the desired attitude. Simulation results show that the proposed FTC method guarantees good tracking performance in the presence of variable mass, faults and disturbances.

Reis, Yu, Cabecinhas and Silvestre [3] address the problem of slung load transportation for an underactuated quadrotor requiring the damping of oscillations and external disturbances. The position control strategy involves a sliding mode controller that computes a vectored thrust actuation to damp out the system's oscillations. To ensure good attitude tracking performance, conventional backstepping methods and a sliding mode controller built intrinsically in SO(3), are exploited to control the vehicle's angular velocity and to produce torque commands, respectively. Simulation and experimental results validate the robustness of the proposed technique in a trajectory tracking scenario.

Yu, Xu, Zhang, Jiang and Su [4] investigate the fault-tolerant containment control (FTCC) problem for a group of fixed-wing UAVs and consider fault tolerance and collision avoidance simultaneously. In this article, a fractional-order (FO) FTCC scheme is proposed to steer all follower UAVs into the convex hull formed by the leader UAV with the involvements of FO calculus, disturbance observers (DOs), and interval type-2 fuzzy neural networks. In this scheme, FO sliding-mode surfaces with artificial potential functions are designed to revamp the filtered containment errors, and the DOs with FO calculus are constructed to estimate the FO lumped disturbances involving faults and external disturbances. To compensate for the DO estimation errors, IT2FNN learning mechanisms are introduced to improve the FTCC capability. Simulation results show that all follower UAVs successfully converge into the convex hull spanned by the leader UAVs without collisions even when a portion of the UAVs encounter faults.

Labbadi, Defoort, Incremona and Djemai [5] propose a FO command filtered-based recursive finite-time control using a non-singular TSM technique for high-order uncertain nonlinear systems under disturbances with unknown bounds. The proposed control is developed to go beyond the limitations of existing finite-time tracking controllers. In this work, the reaching phase is removed, and a chattering alleviation property is achieved. This fractional-order control strategy has been applied to quadrotor UAVs in different scenarios affected by disturbances with increasing amplitudes and frequencies. Simulation results demonstrate the effectiveness of the proposal strategy even in comparison with an existing approach in the literature.

Zhou, Yang, Strampe and Klingauf [6] establish a mathematical model of a hybrid quad-plane UAV characterized by complex structures, high nonlinearity, strong coupling, and various flight regimes involving hover, transition, and fixed-wing flight. A cascade flight control architecture for quad-plan UAVs is created using the incremental nonlinear dynamic inverse (NDI) method to improve the path following performance. To improve the control performance, reference models are added to the inner loops to shape the input commands and to provide feedforward control. A comparative study, involving active disturbance rejection control, proportional-integral-derivative control and the INDI-based control law, demonstrates the design efficacy.

Li, Liu, Ming, Li, and Zhang [7] address an adaptive actuator fault-tolerant control problem and propose a model reference-based adaptive nonlinear dynamic inversion (NDI) scheme to improve the robustness of the flight control system. In this scheme, the modified piecewise-constant adaptation law is used to improve the estimation accuracy of disturbances and a low pass filter is created to prevent the aircraft from oscillating because of the fast adaptation. The hardware-in-the-loop simulation results demonstrate fault tolerant flight control performance in the face of actuator loss of effectiveness and lock in place despite variations of the centre of gravity.

This special issue also considers the development and application of a reinforcement learning-based control for aerial robots. Liu, Li, Xiao, Ran and Zhang [8] propose a reinforcement learning based control scheme which handles the tracking problem of a quadrotor UAV under external disturbances. A feedforward control technique is used to compensate the raw error dynamics and two appointed-fixed-time observers are proposed to estimate the disturbances forces and torques, respectively. Two control policies are proposed to balance the control cost/performance and two critic neural networks are utilized to replace the traditional actor-critic networks for approximating the solutions of Hamilton-Jacobi-Bellman equations. Furthermore, two novel weight update laws are designed independent of the persistent excitation condition. Simulation results show the superiority of the developed scheme in balancing control cost and control performance.

Zhang, Zeng, Guo and Ma [9] propose a reinforcement learning-based guidance law and apply it to the collision avoidance during a Mars powered decent phase despite the mass variation of the lander. This work formulates this specific scenario into a constrained nonlinear optimization problem and solves it using a critic neural network. To cope with the position constraint (i.e., the glide-slope constraint) and the thrust force limit constraint, a modified cost function is proposed, and the associated Hamilton-Jacobi-Bellman equation is solved online without using an actor neural network, which significantly reduces the computational burden. Simulation results show the effectiveness of the proposed method.

Rong, Chou and Jiao [10] address the FTC problem in the situation where a fully actuated UAV performs contact-based aerial manipulation tasks despite unknown boundaries. In this article, a disturbance observer based sliding mode impedance controller is proposed and its super-twisting gains calculated in an adaptive sense. To avoid overestimation of the unknown disturbance bounds, an adaptive third-order extended state observer is developed to actively estimate the disturbances and to compensate for the controller, without the knowledge of the disturbance bounds. In the numerical simulation, the control scheme is tested under severe conditions in which the model uncertainties, external disturbances, and actuator faults are all included during a push-and-slide physical interaction task.

The topic of time delay estimation is also involved in this special issue. Jing, Chen and Liu [11] develop a two-stage algorithm to identify a time-delay ARX model. In this development, a 2-copula criterion-based time-delay estimation method and a multi-gradient algorithm with adaptive stacking length are studied. This algorithm accelerates the traditional stochastic gradient algorithm after taking into account several recent gradients in each iteration. The stacking length, which represents the number of the gradient used in a step, is determined by the Armijo criterion. Finally, the proposed algorithm is validated using the UAV dataset.

In this special issue, a mobile multi-agent sensing problem is also studied. Kim, Lee and Moon [12] introduce an exact solution algorithm to find a near optimal solution to reduce the probability of situations in which severe or catastrophic consequences are detected by agents. Another contribution of this article is to deal with the risk-averse decision and its exact algorithm for the problem under uncertain situations (errors with sensors). A case study associated with forest fires is used to show the validity and applicability of the algorithm.

Yang, Hou and Jin [13] propose two robust model-free adaptive control (RMFAC) schemes for the longitudinal flight control of a flapping wing micro air vehicle (FWMAV) with measurable and unmeasurable wind disturbances. In this scheme, the FWMAV system with measurable disturbance is transformed into an equivalent data model by using a disturbance-related full-form dynamic linearization (DFFDL) technique. Furthermore, the robust model-free adaptive controller is derived based on a control criterion function and the extended PG vector is estimated using a projection algorithm. In this study, the stability of the DFFDL-RMFAC scheme is rigorously analysed and simulation results verify the effectiveness of the schemes.

Shastry and Paley [14] develop and experimentally evaluate a comprehensive system identification framework for UAV control in wind. The framework estimates model parameters before the implementation of a nonlinear controller. Specifically, the inertial parameters of the UAV are estimated using a frequency-domain linear system identification program, and the drag-force coefficients and external wind are estimated using a square-root unscented Kalman filter. Flight experiments illustrate the nonlinear controller's tracking performance and gust rejection capability.

Nejabat and Nikoofard [15] develops a decentralized control methodology for a multi-agent UAV system in a leader-follower configuration. Primary model predictive control (MPC) is proposed to steer the error signal to the origin. Furthermore, a robust modification is also investigated using a tube definition in the presence of high-frequency noise and external disturbances. The closed-loop system architecture, which switches between the primary MPC controller to the tube-MPC controller, provides a more energy-efficient outcome compared to the single mode controller. In addition, the possibility of changing leader is investigated using flexible formation theory. The numerical simulation involves the comparison between a conventional proportional-integral-derivative (PID) and the Tube-MPC controller.

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