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Decentralized fault-tolerant cooperative control of multiple UAVs with prescribed attitude synchronization tracking performance under directed communication topology

Key words: Fault-tolerant control; Decentralized control; Prescribed performance; Unmanned aerial vehicle; Neural network; Disturbance observer; Directed topology

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Motivation

1. The implementation of multiple unmanned aerial vehicles (multi-UAVs) instead of a single UAV increases system reliability and efficiency and reduces the overall cost of a mission.
2. For the reduction of communicational and computational burdens in cooperative control of multi-UAVs, the decentralized control architecture is more efficient than the centralized control architecture.
3. For the formation flight of multi-UAVs, actuator faults may cause performance degradation or even lead to a chain of failing UAVs.
4. The emphases of most existing results reported on fault-tolerant control (FTC) of a single UAV or fault-tolerant cooperative control (FTCC) of multi-UAVs are placed on how to guarantee the tracking error for converging to a bounded region or an origin, which can be seen as research handling only steady-state performance.

Main idea

1. The FTCC scheme is investigated for multi-UAVs in a decentralized communication network with a directed information flow, rather than a centralized communication topology.
2. Unknown terms due to the inherent nonlinearities in UAVs and actuator faults are compensated for by the composite approximators constructed by neural networks (NNs), disturbance observers (DOs), and prediction errors.
3. Transient fault-tolerant synchronization tracking performance is considered by incorporating a prescribed performance function.

Method

1. To constrain the synchronization errors within the prescribed bounds, synchronization errors are first transformed into a new set of error variables by the prescribed performance functions.
2. NNs are used to approximate unknown nonlinear terms due to the nonlinearities inherent in UAVs and the loss of control effectiveness actuator faults.
3. DOs are used to compensate for NN approximation errors and bias faults.
4. Prediction errors are incorporated into NN adaptive laws and DOs to enhance the approximation abilities.

Major results (1/4)

The bank angles, angles of attack, and sideslip angles of UAVs 1-4 can successfully track the bank angle, angle of attack, and sideslip angle references (μ_{id}, α_{id}, β_{id}), respectively, even when UAV 1 encounters an aileron fault at *t*=3 s, UAV 2 encounters an elevator fault at *t*=8 s, and UAV 3 confronts a rudder fault at *t*=12 s.

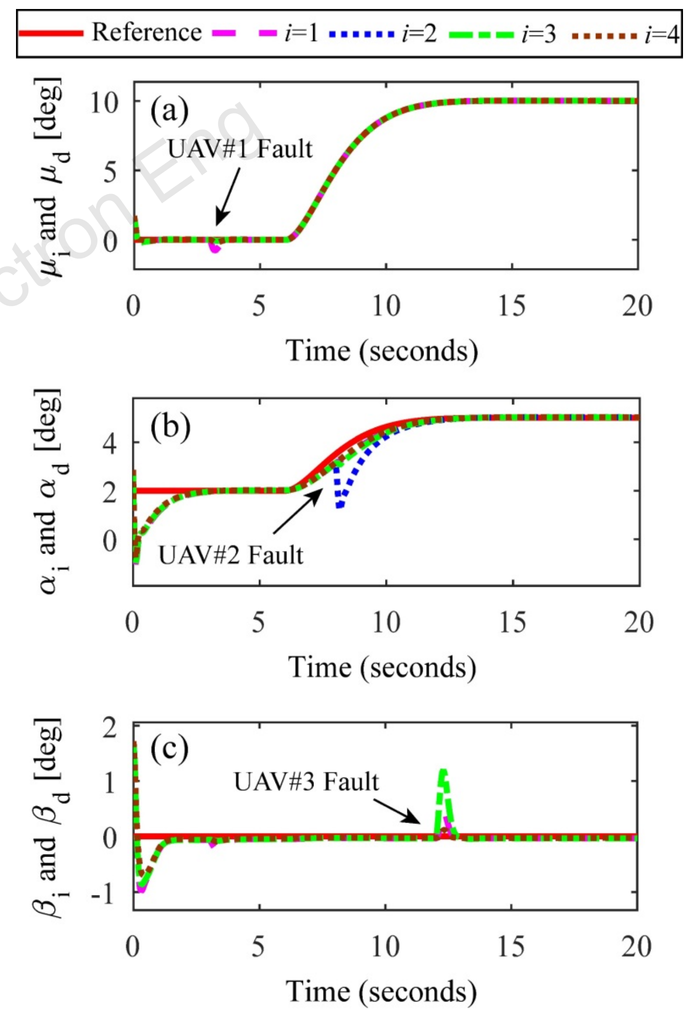

Fig. 2 Bank angles μ_i (a), angles of attack α_i (b), and sideslip angles β_i (c) of four UAVs (*i*=1, 2, 3, 4)

Major results (2/4)

The bank angle, angle of attack, and sideslip angle synchronization tracking errors strictly evolve in the region between the prescribed upper bound and the lower bound, even in the presence of actuator faults.

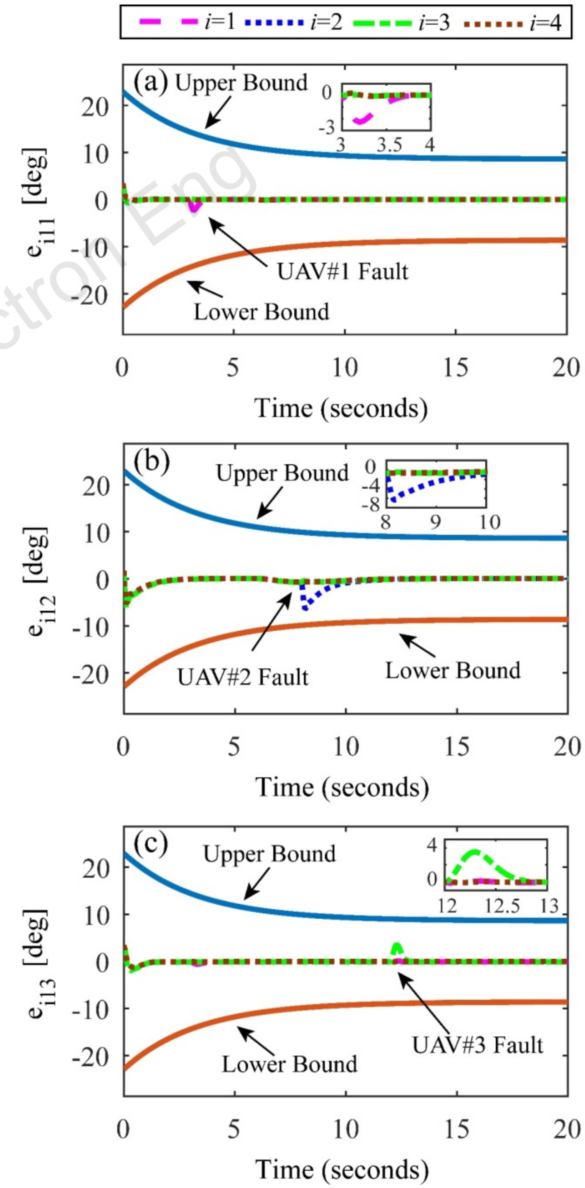

Fig. 4 Attitude synchronization tracking errors e_{i11}, e_{i12}, e_{i13} of four UAVs (*i*=1, 2, 3, 4)

Major results (3/4)

The nonlinear functions $\boldsymbol{f}_{i1}$ (i=1, 2, 3, 4) are well approximated using NNs and DOs even when aileron, elevator, and rudder faults are encountered by UAVs 1, 2, and 3, respectively.

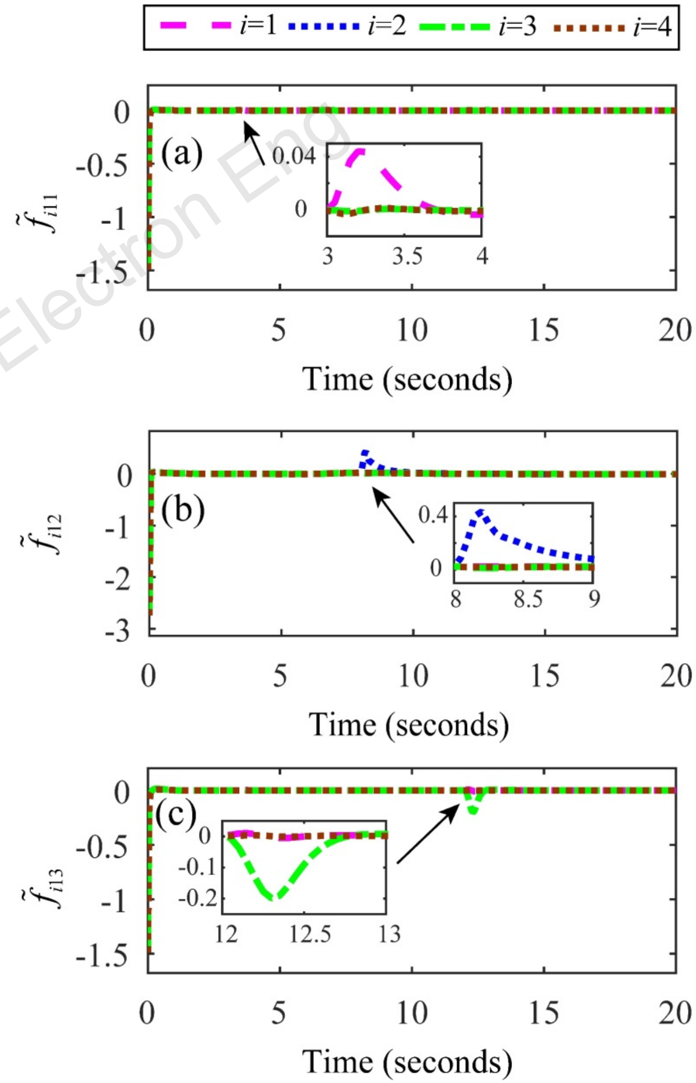

Fig. 6 Approximation errors of neural networks and disturbance observers under Eq. (30) and law (34): (a) $\tilde{f}_{i11}$; (b) $\tilde{f}_{i12}$; (c) $\tilde{f}_{i13}$ (i=1, 2, 3, 4)

Major results (4/4)

When UAVs 1, 2, and 3 encounter the aileron, elevator, and rudder faults, slightly degraded but acceptable approximation performances are induced. Under the proposed NNs and DOs, the approximation errors $\tilde{\Xi}_{i1}$, $\tilde{\Xi}_{i2}$, and $\tilde{\Xi}_{i3}$ are pulled into the small regions containing zero again.

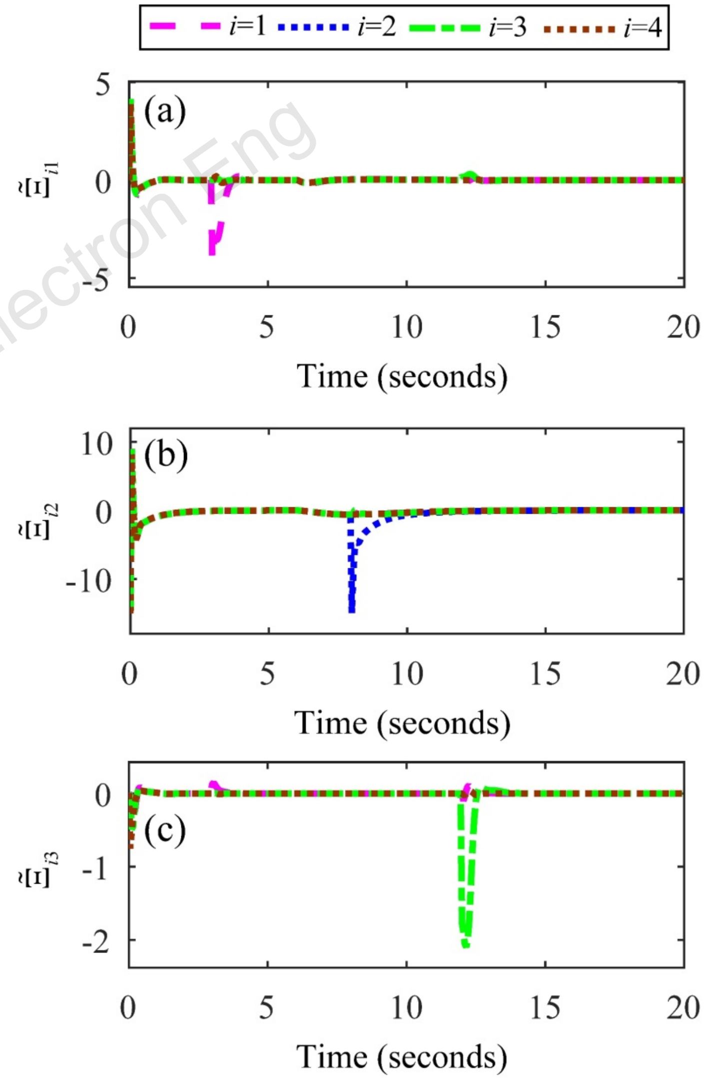

Fig. 7 Approximation errors of neural networks and disturbance observers under Eq. (42) and law (46): (a) $\tilde{\Xi}_{i1}$; (b) $\tilde{\Xi}_{i2}$; (c) $\tilde{\Xi}_{i3}$ (*i*=1, 2, 3, 4)

Conclusions

1. A decentralized FTCC scheme with prescribed attitude synchronization tracking performance has been proposed for a group of UAVs in a directed communication network.
2. NNs and DOs are combined to approximate unknown nonlinear functions, as well as nonlinear terms due to actuator faults. Moreover, the prediction errors are integrated into the adaptive laws and DOs to enhance the approximation ability.
3. By imposing the prescribed performance functions on the attitude synchronization errors, prescribed synchronization tracking control can be achieved.
4. It has been proven theoretically that the proposed control scheme can make the attitudes of all UAVs synchronously track their attitude references. Simulation results on a network of four UAVs have demonstrated the effectiveness of the proposed control scheme.