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Adaptive tracking control of high-order MIMO nonlinear systems with prescribed performance

Key words: Adaptive tracking control; Prescribed performance; Input saturation; Disturbance observer; Neural network

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Motivation

1. The tracking control of multi-input multi-output (MIMO) nonlinear systems has attracted a great deal of attention over the past few decades because it is common in practice.
2. For disturbance observer design, up to now, several methods have been applied to handle the external disturbances. However, the performance of the observer is always ignored. A high-performance disturbance observer needs to be investigated further.
3. A question remains, that is, how to achieve prescribed performance tracking control of high-order MIMO nonlinear systems in the presence of uncertainties, disturbances, and input constraints.

Main idea

1. We formulate and solve the tracking control problem with prescribed performance for high-order MIMO nonlinear systems, where the system uncertainties and external disturbances are also considered.
2. A novel neural network (NN) disturbance observer is presented to handle the system uncertainties and external disturbances. Compared with the existing schemes, the convergence time is proven to be limited, and a continuous signal is achieved to avoid chattering problems.
3. With the error transformation, a new solution is given to guarantee the predefined tracking performance. Furthermore, the input saturation is considered as an extension.

Method

1. In this study, the radial basis function (RBF) NN is chosen to construct an NN observer for disturbance estimation. A continuous signal in the finite-time observer is achieved to avoid chattering problems. Moreover, the disturbance observer design is separated from the controller design, and remains flexible to integrate with other control laws.

2. To achieve the prescribed performance, the original system is transformed by an error transformation function. On that basis, a barrier Lyapunov-based backstepping controller is designed to realize the proposed control objective.

Method (Cont'd)

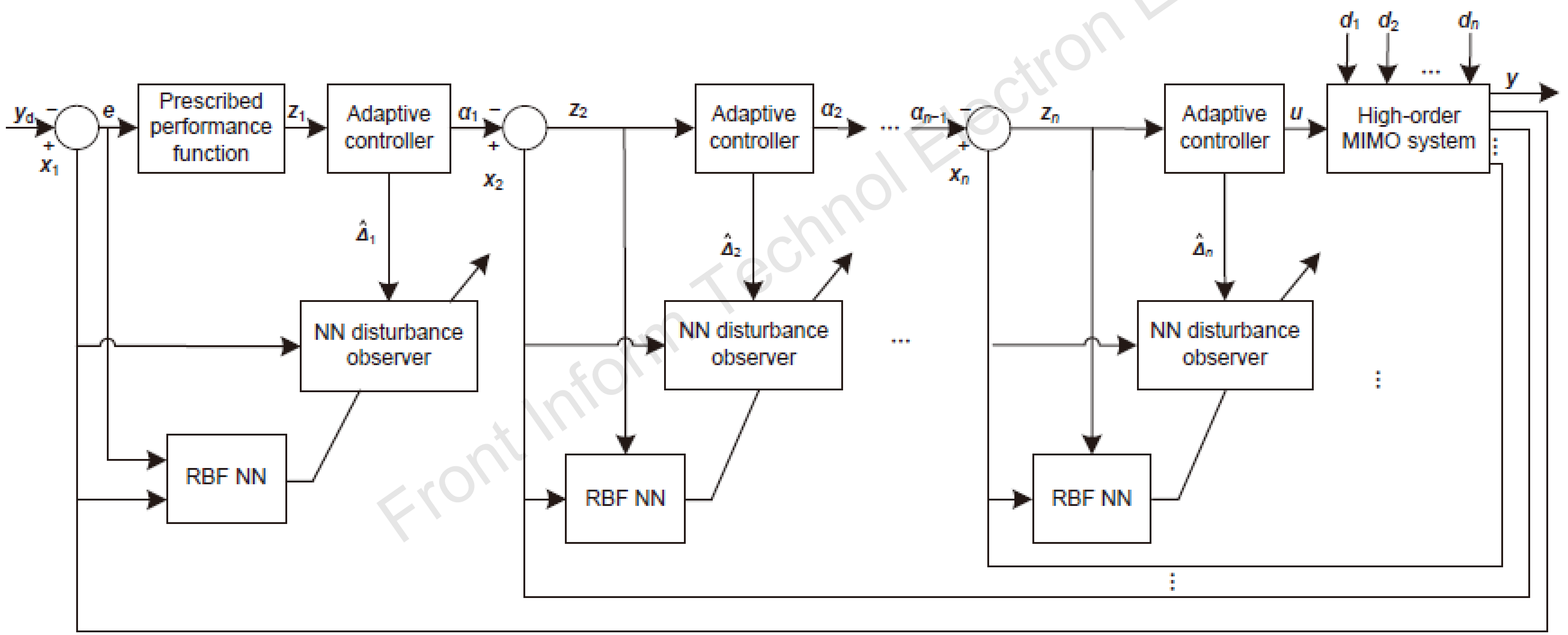

Fig. 1 Block diagram of the developed control strategy

Major results

Theorem 1 Consider the high-order MIMO nonlinear system (1), if the NN disturbance observer (14) is used to estimate the total disturbance with the adaptive law (16), the estimation errors s_i will converge to a very small neighborhood of the origin in finite time.

Major results (Cont'd)

Theorem 2 Consider a class of high-order MIMO nonlinear systems (1) with system uncertainties and unknown external disturbances satisfying Assumptions 1–3. With the finite-time NN disturbance observer (14), adaptive law (16), and the proposed control law (48), the closed-loop system output can track the desired trajectory with all the signals bounded, and the transformed tracking error z_i is bounded. For any initial error satisfying the initial condition, the tracking error e_i can be guaranteed to be within the prescribed tracking performance.

Major results (Cont'd)

Theorem 3 Consider a class of high-order uncertain MIMO nonlinear systems (1) with unknown external disturbance and input saturation satisfying Assumptions 1–3. With the finite-time NN disturbance observer (14), adaptive law (16), and the proposed control law (64), the closed-loop system output can track the desired trajectory y_{d} with all signals bounded, and the transformed tracking error z_1 is bounded. For any e_{i0} that satisfies the initial condition, the tracking error e_i can be guaranteed to be within the prescribed tracking performance.

Major results (Cont'd)

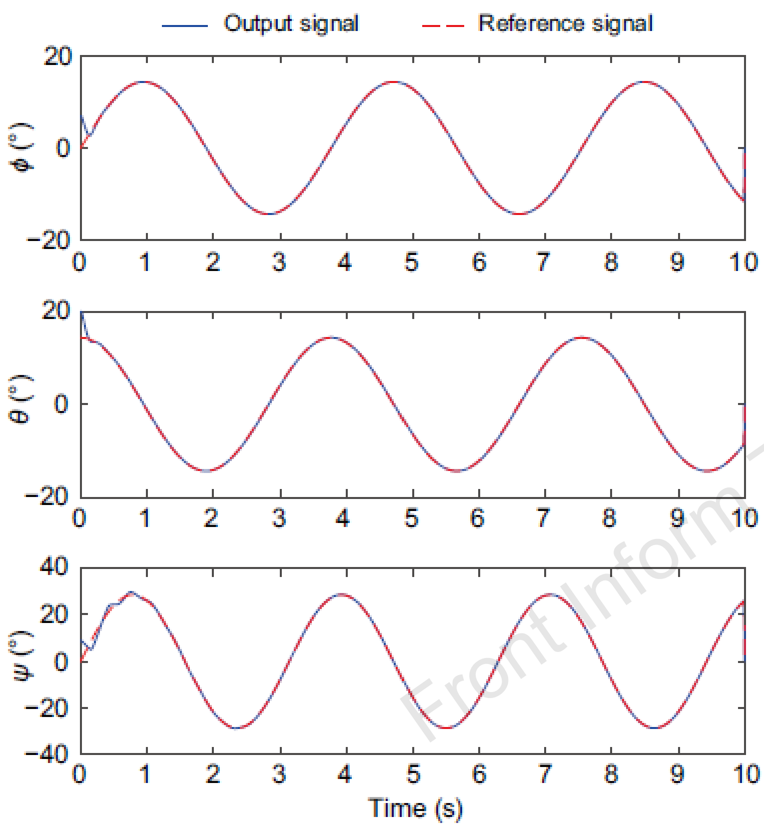

Fig. 2 Trajectories of the attitude angles of the quadrotor (blue line) along with the desired trajectory (red dashed line) under control input u

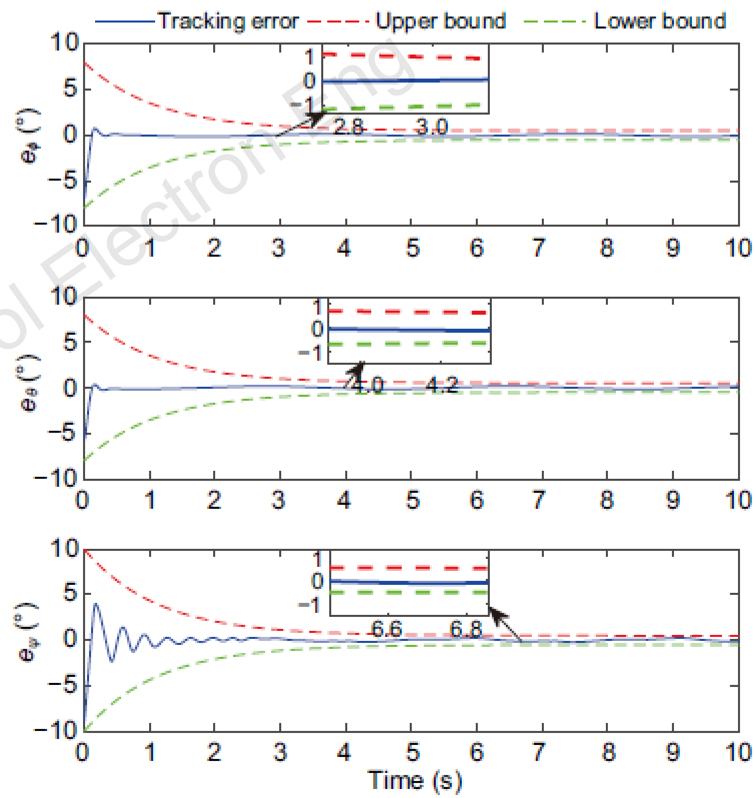

Fig. 3 Tracking error evolution with the prescribed performance under control input u

Major results (Cont'd)

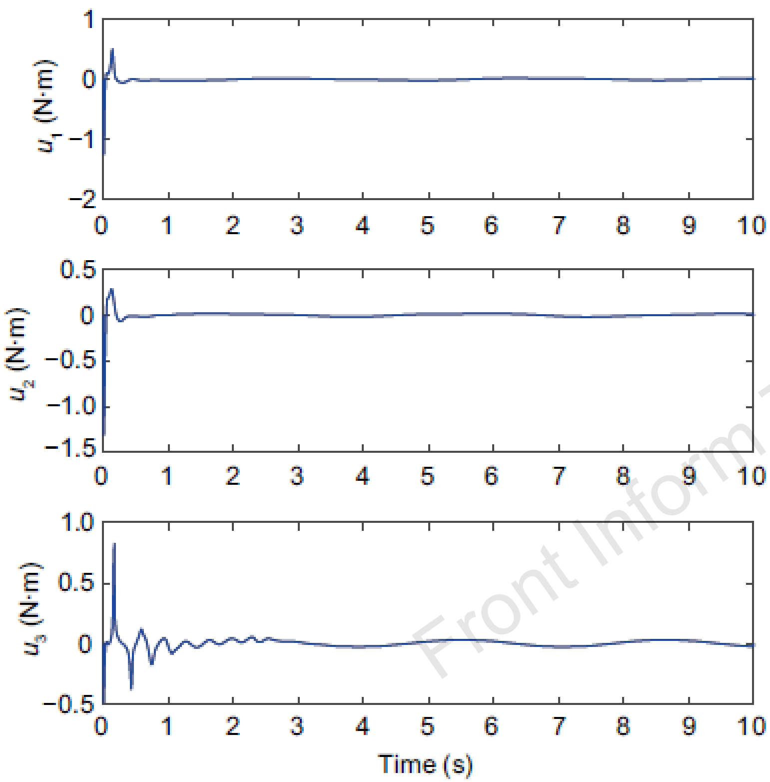

Fig. 7 Control demands u for attitude angles without input saturation

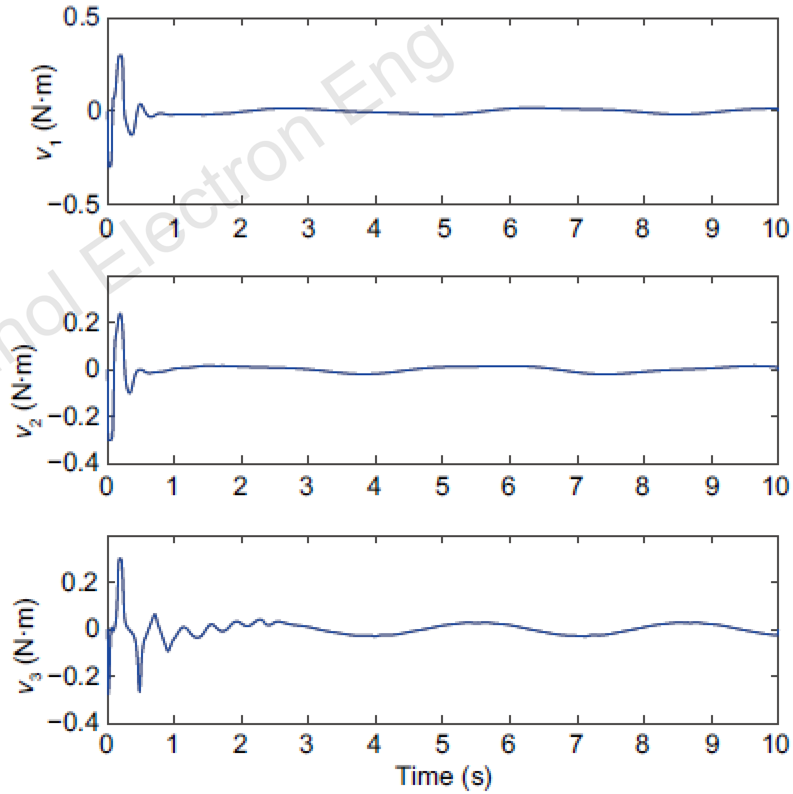

Fig. 8 Control demands v for attitude angles with input saturation

Major results (Cont'd)

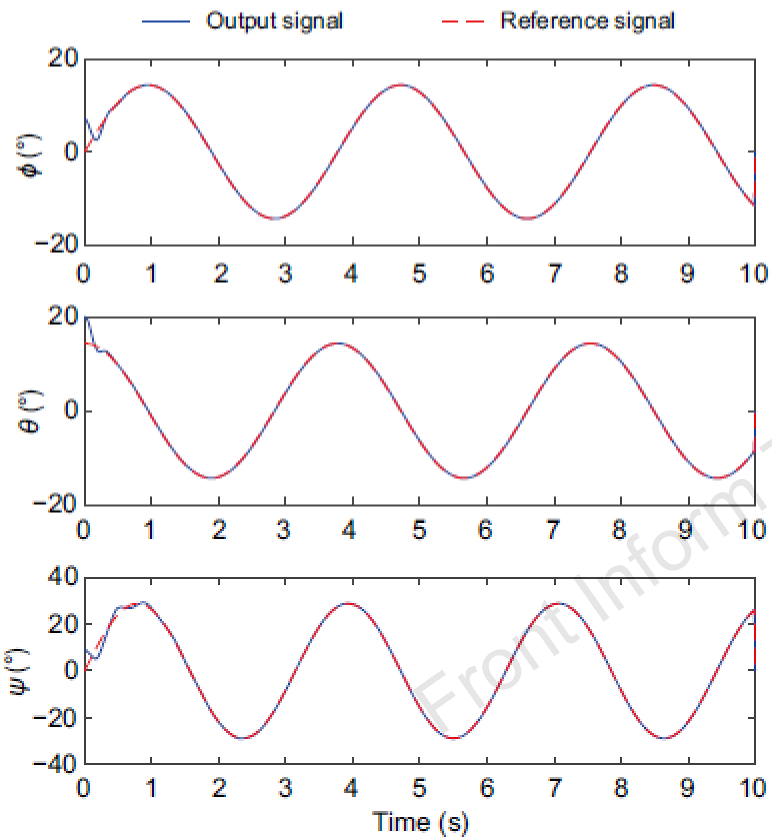

Fig. 9 Trajectories of the attitude angles of a quadrotor (blue line) along with the desired trajectory (red dashed line) under input v

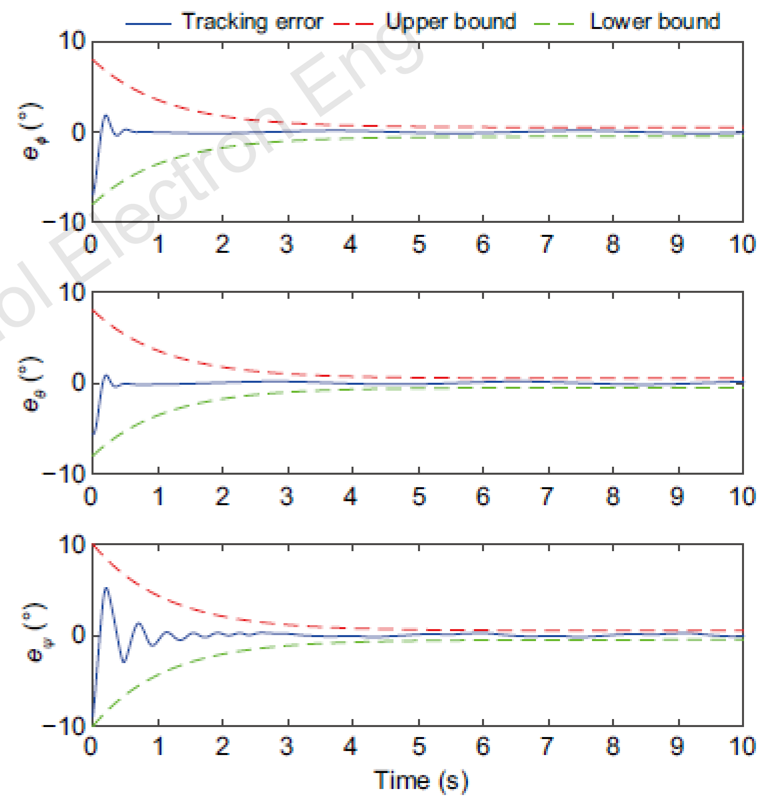

Fig. 10 Tracking error evolution with the prescribed performance under input v

Conclusions

1. In the control design, we have presented a novel NN disturbance observer to estimate the uncertainties and disturbances in finite time.

2. Using the backstepping technique and a barrier Lyapunov function, an adaptive tracking control method has been proposed which could guarantee the prescribed performance of the tracking error and the boundedness of the closed-loop signals.

3. Future research may focus on the observer-based control strategy for completely unknown systems and nonlinear multi-agent systems.

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