

Chapter 9

Summary and future perspectives

In this concise chapter, we summarize the work accomplished in the thesis, highlighting its principal contributions and acknowledging its limitations. Additionally, we delve into potential avenues for future research exploration.

9.1 Research summary

This thesis extensively focused on the development and application of prescribed-time control methodologies designed explicitly for nonlinear systems. The research addressed various challenges in different domains, including adaptive backstepping control, twin-rotor helicopters, uncertain systems, multi-agent systems, and optimal control. The key contributions and findings of each chapter are summarized in detail as follows:

Chapter 3 introduced a novel prescribed-time adaptive backstepping control methodology for a class of nonlinear systems. The approach integrated backstepping techniques with adaptive laws to achieve prescribed-time convergence. Theoretical analysis and extensive simulation studies were conducted to validate the effectiveness and robustness of the proposed methodology in achieving prescribed-time convergence.

Chapter 4 extended the prescribed-time adaptive backstepping control approach to the control of twin-rotor helicopters. The primary objective was to achieve prescribed-time convergence of the helicopter's state variables, thereby enabling precise and timely maneuvering. Simulation results demonstrated the capability of the control strategy to govern twin-rotor helicopters and effectively achieve the desired prescribed-time convergence.

In Chapter 5, the thesis aimed to address the inherent uncertainties in control systems and effectively manage input constraints. An adaptive prescribed-time constrained feedback

control strategy was proposed specifically for uncertain twin-rotor helicopters to accomplish this objective. The methodology involved the integration of adaptive prescribed-time control techniques with constraints on system inputs, resulting in a control approach that not only ensured safe operation but also optimized efficiency even in the presence of uncertainties. The proposed control approach underwent rigorous examination to assess its effectiveness and robustness. This evaluation encompassed a combination of theoretical analysis, extensive simulation studies, and practical experimental evaluations. The theoretical analysis provided valuable insights into the stability and performance guarantees of the control strategy under uncertain conditions. Simulation studies were conducted to thoroughly test and validate the methodology across various uncertain scenarios, providing compelling evidence of its effectiveness in achieving prescribed-time convergence while adhering to input constraints. Furthermore, practical experimental evaluations were performed to showcase the real-world applicability and performance of the control approach in effectively controlling uncertain twin-rotor helicopters.

Chapter 6 introduces a prescribed-time adaptive estimator-based robust control strategy for the DC-DC boost converter, addressing challenges posed by load resistance and input voltage fluctuations. The approach involves employing an adaptive law-based prescribed-time state estimator and sliding-mode control to achieve prescribed-time convergence. Extensive theoretical analysis establishes that the proposed scheme effectively regulates the desired voltage tracking within the specified time frame, showcasing a notable feature of the developed control strategy. To validate the efficacy of the designed control scheme, simulations and experiments are conducted, involving variations in both input voltage and load resistance. In both scenarios, the proposed control scheme consistently demonstrates desirable performance.

Chapter 7 centered around the domain of multi-agent systems and introduced an adaptive neural network-based prescribed-time consensus algorithm specifically designed for uncertain nonlinear multi-agent systems. The algorithm utilized neural networks to dynamically learn and update control laws, thereby enabling prescribed-time convergence even in the presence of uncertainties. Theoretical analysis and extensive simulation studies were conducted to thoroughly examine and validate the effectiveness and practicality of the proposed algorithm in achieving prescribed-time consensus among multiple agents. The results demonstrated the algorithm's capability to robustly achieve the desired prescribed-time convergence in uncertain and nonlinear multi-agent systems, offering valuable insights into the applicability and potential of adaptive neural network-based approaches in this domain.

In Chapter 8, the thesis explored the realm of prescribed-time optimal control for nonlinear systems. Control strategies were developed to optimize system performance within specified

time intervals. The approaches involved the incorporation of appropriate cost functions and constraints to achieve prescribed-time optimal control. Theoretical analysis, simulation experiments, and comprehensive evaluations showcased the effectiveness of the proposed approaches in achieving optimal performance within prescribed time limits.

Overall, this thesis made significant contributions to the field of prescribed-time control for nonlinear systems. By addressing various challenges across different domains, it provided valuable insights and methodologies for achieving prescribed-time convergence, handling uncertainties, enabling consensus in multi-agent systems, and optimizing performance within specified time intervals.

9.2 Limitations and future investigations

While this thesis has made notable contributions to the field of prescribed-time control, it is important to acknowledge that the proposed design also presents certain limitations, indicating opportunities for further advancements. Consequently, the following issues and potential areas for future research and development can be identified:

- The generalization capability of adaptive prescribed-time control methodologies can be a limitation. The control approach may be designed and validated for a specific system or a set of conditions. However, ensuring that the control strategy can adapt and generalize to different operating conditions, system variations, or unforeseen scenarios remains a challenge. Additional research is needed to enhance the adaptability and robustness of adaptive prescribed-time control approaches across a broader range of system dynamics and uncertainties.
- Investigating the integration of model predictive control techniques into adaptive prescribed-time control methodologies could yield significant benefits. Model predictive control (MPC) leverages a predictive model of the system to optimize control actions over a future time horizon. By incorporating MPC, the adaptive prescribed-time control approach can potentially achieve improved tracking, disturbance rejection, and handle constraints more effectively.
- Exploring the integration of sliding mode control techniques with adaptive prescribed-time control methodologies can offer enhanced robustness against uncertainties and disturbances. SMC is known for its ability to maintain stability even in the presence of system uncertainties. By combining SMC principles with adaptive prescribed-time control, the

resulting approach may exhibit superior robustness and tracking performance.

- Leveraging machine learning algorithms, such as data-driven control or reinforcement learning, within adaptive prescribed-time control methodologies can introduce adaptability and learning capabilities. By allowing the control system to learn from data and adjust its control actions accordingly, machine learning-based control approaches can potentially improve performance and adapt to varying system dynamics and uncertainties.
- Extending the prescribed-time control methodologies to networked systems, such as distributed control networks and interconnected systems, would be an interesting direction for future research. Addressing the challenges associated with communication delays, limited bandwidth, and network topology would be crucial in achieving prescribed-time convergence in such systems.
- Integrating prescribed-time control methodologies with existing industry standards and regulations would be important for their practical adoption. Ensuring compatibility and compliance with safety standards, reliability requirements, and operational constraints would enhance the applicability and acceptance of the proposed control strategies in real-world applications.
- Exploring the interaction between prescribed-time control systems and human operators is another area for future research. Investigating the design of intuitive interfaces, feedback mechanisms, and shared control strategies would be crucial in developing human-centered prescribed-time control systems that are user-friendly and easy to operate.