Chapter 5

Conclusion and Future Scope

5.1 Research Summary

This thesis work considers the SOF design problems arising in control theory. In this context, first new sufficient LMI conditions are derived for designing the SOF controller for both CT and DT systems ensuring some performance measure in terms of robustness and transient behavior. Second, the design SOF problem is extended to PID controller design problem and a class of polytopic systems. Finally, the application of the developed theories are validated through implementation on real-time hardware setups. The following section emphasizes chapter-wise main contributions of this work.

5.2 Thesis Contributions

The main contribution of this thesis are summarized as follows:

- New LMI criteria for SOF design are derived for CT systems that can be used for both the centralized and the decentralized control design. The development involves a decomposition of Lyapunov matrices and deriving LMI criteria ensuring robust performances. In addition, pole-placement criteria are added in the design criteria to improve the system transient behavior. The SOF design condition is extended to the PID controller design problem for higher order MIMO systems. The design approach is more suitable for easy tuning of multivariable PID controller gains. Further, the SOF design problem is extended to the class of uncertain polytopic systems. Sufficient conditions are derived for designing SOF controller for CT systems with matched output matrix both with and without actuator saturation by introducing an auxiliary matrix variable and decomposing this variable instead of the Lyapunov matrix. The efficacy of the proposed design criteria are illustrated through numerical examples.

- New LMI conditions are derived for designing H_2 and H_∞ SOF controllers for DT systems as well. Two design criteria have been proposed. First design criterion is developed through appropriate use of bounding inequalities. It involves certain relaxations of the LMI variables leading to less conservative LMI design criteria. The second design criterion is derived using decomposition of an auxiliary matrix. The decomposition facilitates linearization of nonlinear term of reduced size in the matrix inequality to obtain linear matrix inequality criteria. This leads to less conservative results than the design conditions developed previously. A transformation framework is also proposed for designing dynamic output feedback controller using the SOF design method. In addition, a new ellipse-segment approximation is proposed to approximate the non-convex region of the constant damping ratio locus in DT systems. LMI criteria for state and output feedback (static as well as dynamic) controllers are derived to locate the closed-loop poles of DT uncertain polytopic systems in desired damping region. The effectiveness of the developed conditions are illustrated through numerical examples.

- At last, methodologies are presented for designing robust LMI based PI controller for industrial and aerodynamics applications and implementation of so designs on real-time hardware setups, i.e., Quanser make coupled tank system and a 2-DOF helicopter. A new approach for handling nonlinear CT systems in the form of polytopic model has been proposed. The nonlinear system model is represented in a linear form with parametric uncertainties that does not involve neglecting any higher-order term. Additionally, regional pole placement criterion considered in the design improves the closed-loop transient behavior of the CT systems. Further, a robust qLPV PI controller is designed for tracking control of a TRMS. The system is modeled as a qLPV polytopic one, without any approximation of the higher order terms. This approach, along with adaptable qLPV structure prevents any additional cross-coupling appearing between the dynamics of both the pitch and yaw planes, thereby reducing the cross coupling through the controller gains. The controller gain is kept within practical limit by incorporating actuator saturation criterion.

Next, the efficacy and application of the SOF controller design for polytopic systems in the presence of actuator saturation presented in chapter 2 is illustrated through the implementation on hardware setup of 2-DOF helicopter. Experimentals are carried out to demonstrate the effectiveness of proposed design method. Further, an application and effectiveness of the proposed control strategy presented in chapter 3 is demonstrated for a boost converter, even for PI controller design in order to improve the transient behavior of the boost converter subject to variation in input voltage and load resistance. Simulation results are presented to show its effectiveness.

5.3 Suggestions for future work

As we all know that the problem of designing the SOF controller is a challenging and tedious task, it is still an open area of research. The criteria proposed in this work can be extended to more complex systems. Also, there are some shortcomings in the proposed work, and there exists scope for further improvements. These issues and future work can be pointed out as the following.

- In this work, the SOF controller design criteria are proposed for CT polytopic systems subject to actuator saturation with the assumption that the output matrix C is fixed. Relaxing this assumption and developing the SOF controller for general polytopic systems remains a future problem.

- In this work, we have only proposed the criteria for SOF controller design for the CT polytopic systems under actuator saturation. This proposed methods can be extended for the DT systems incorporating the uncertainties.

- The SOF problem for negative imaginary systems with collocated sensors and actuators and positive systems such as biological systems can be extended to robust control design incorporating uncertainties.

- Anti-windup compensation is often used [14, 161, 162] to deal with the saturation problem using the information of whether the actuator is saturated. This improves the transient response of the states while enlarging the region of attraction of the closed-loop system. This present work may be extended by incorporating anti-windup compensation.

- In this work, pole-placement criteria through state and output feedback controller in the newly approximated region for the uncertain DT systems have been proposed without considering performance measure. So, future work will be to augment more performance criteria in design, such as H_2, H_∞ control [164] in multi-objective framework.

- The present work can be extended to design data-driven control for the data driven systems, i.e., systems with information of input-output only. In the literature [185, 186], only the data-driven control with state feedback has been carried out. This design problem is open for the SOF case, incorporating some H_2 and H_∞ performance criteria.

- Proposed SOF controller design methodology can be extended for descriptor Systems, Networked control systems, H_∞ filtering design problem and implementation of designed controller on power electronics, robotics, aerodynamics and power system applications.

- In the application work presented in chapter 4, the velocity measurement is obtained using a derivative filter, which is responsible for introducing additional noise into the system. Future work will consider eliminating the effects of such noisy measurements for smooth tracking. Additionally, incorporating actuator rate limits and actuator faults/failures within a stochastic framework discussed in [179, 180], in conjunction to amplitude saturation will be looked into.

- Throughout this work, it has been assumed zero initial conditions for computing the H_∞ performance of the system. In future, the problem of H_∞ based SOF controller design with non-zero initial conditions can be considered.