Chapter 7

Conclusion

This thesis addresses some concerns and restrictions in the conventional SMC. These are tackled from theoretical as well as implementation perspective. The systems considered are all nonlinear with matched and/or mismatched uncertainty. The estimation methods used are UDE, DO and EID.

7.1 Overall Summary

The main conclusions that result from the work presented in this thesis are broadly summarized below.

1. The method of UDE aids in mitigating the effect of chatter in conventional sliding mode. The use of UDE gives a better trade-off inside the boundary layer and this trade-off is improved by using a higher order UDE.

2. A modified sliding surface handles the problem of large initial control associated with UDE. The UDE based control enforces sliding, without using discontinuous control and without requiring any knowledge of uncertainties or their bounds.

3. The control law is made implementable by simultaneous estimation of states and uncertainties.
4. The UDE is able to compensate nonlinear uncertainty even in input vector to enable a robust SMC law. The efficacy of this design is confirmed for an inverted pendulum control.

5. The method of EID enables SMC to compensate mismatched disturbance. The integral action in conventional EID based control is avoided by the use of SMC for nominal control.

6. The method of EID is able to compensate state-dependent uncertainties. A higher-order filter facilitates improvement in the performance of EID based control.

7. The EID combined with DO can robustify the control of uncertain nonlinear systems. An extended DO is successful in improving the estimation accuracy of EID further by giving the estimate of derivatives of disturbance as well.

8. The efficacy of SMC with EID in applications for anti-lock braking system and active steering control is proved. The results prove that the system is robust to different friction models.

9. The use of δ-operator in conjunction with a new sliding condition enables complete and seamless unification of control law and UDE.

10. The UDE enables reduction of quasi-sliding band for a given sampling period. The sliding width is significantly reduced by using a second-order filter.

11. The efficacy of discrete SMC is proved for a motion control application.

12. The sliding variable, uncertainty estimation error and state estimation error are ultimately bounded in all cases. It is proved that the bounds can be lowered by appropriate choice of control parameters.

The core idea underlying all the aforementioned work is the estimation of states, uncertainty and disturbance for robust sliding mode control. The simplicity of control design supplemented by estimation capability of methods like UDE, DO and EID makes this approach an attractive proposition. The applicability of designed control to a wide range of systems shows a promise that uncertainty estimation based control techniques shall be a major topic of interest in robust control.
7.2 Recommendations for Future Work

The work in this thesis can be continued in following direction.

1. The proposed strategies need to be explored for control of under-actuated and non-minimum phase systems.

2. The proposed schemes can be designed for applications in various verticals like power converters, fuel-cells, electro-pneumatic systems, electric drives, smart structures, process control, transportation systems.

3. The proposed schemes can be further robustified by redesigning control to consider unmodeled lags, quantization effects and actuator saturation.

4. The use of nonlinear sliding surface and nonlinear DO offers interesting possibilities for applications with dual objectives.

5. The extension of proposed techniques for terminal sliding-mode and higher-order sliding mode control is also an avenue worth pursuing.

6. The implementation of proposed schemes on various digital platforms i.e. micro-controllers, digital signal processors (DSPs) and field programmable gate arrays (FPGAs) needs to be explored.