CHAPTER 7

CONCLUSIONS

The main focus of the thesis was to investigate the performance of quadratic optimal controllers for tracking and stabilization applications of under actuated system. The major issues that this thesis addressed are twofold: weight selection problem of LQR, and optimal PID tuning using LQR approach for highly oscillatory systems. The classical inverted pendulum mounted on a cart, a benchmark under actuated system, is used to validate the effectiveness of proposed control algorithms. While designing the state feedback controller for stabilization of inverted pendulum, the limitations on the input and track length are not considered, which poses additional problem of generating high control input while improving the speed of response of the system. Hence to address the input and track length constraints, a robust LQR controller is formulated and applied for tracking applications of inverted pendulum. Both the disturbance rejection and the stabilization properties of the controller have been tested using a linear inverted pendulum benchmark system. The disturbance rejection property of the LQR is tested by introducing a noise signal during the stabilization phase, and the ability of the controller to arrest the disturbance in reduced time has also been demonstrated. Both the dynamic and steady state characteristics of the proposed controller are validated with that of the conventional double PID controller, and the experimental results proved that the proposed controller can guarantee the inverted pendulum a faster and smoother stabilization process with less oscillation and better robustness than the double PID controller.
The main attractive feature of LQR is that if the system is a single input single output system, it provides the closed loop system a guaranteed minimum phase margin of $60^\circ$ and an infinite gain margin. This factor has motivated researchers to apply LQR for tuning the gains of PID controller, but most of the existing works are applied to only under damped systems. Hence an attempt has been made to extend the LQR based PID tuning to an over damped systems with sluggish response. The gains of PID controller are initialized as state feedback controller gains, and a new criterion for selecting the weight matrices Q and R of the LQR which will result in desired damping ratio and natural frequency are formulated. The proposed methodology has been validated on a benchmark magnetic levitation system. Both simulations and experiments are carried out for trajectory tracking of magnetic levitation system using LQR based PID tuning. The performance of the controller has been validated using sine, square and saw tooth trajectories. The reduced trajectory tracking error suggests that this approach can be employed for optimally tuning the gains of PID controller.

In the absence of full state vector information, an observer is necessary to estimate the unknown state variables to implement full state feedback control via LQR. Hence, a robust sliding mode observer is formulated using constrained Lyapunov equation for estimating the states of a DC servo system in the presence of disturbance. A sliding surface which can accommodate the unknown inputs present in the system is designed to reduce the estimation error. The performance of the observer has been validated for various test cases.

The most important problem in the design of LQR is the selection of Q and R matrices, but usually the weighting matrices are chosen either based on the experience of the designer or via trial and error approach. In order to address the weighting matrices selection problem of LQR, an
adaptive PSO algorithm has been proposed to optimally select the Q and R matrices of LQR. An important aspect in PSO to find an optimal solution is the proper control of inertia weight because it decides both the global exploration and local exploitation capabilities of the algorithm. Hence, an adaptive inertia weight factor is introduced in the velocity update equation of the conventional PSO to not only improve the search process but also to increase the accuracy of the tuning method. Unlike the conventional PSO in which the weights of particles are varied linearly, in APSO the weights are adaptively tuned based on the success rates of the particles towards the best value. The performance of the APSO has been compared with that of GA and PSO, and the minimized fitness function obtained via APSO is the least of the three tuning methods, which suggests that APSO can provide improved convergence results. Moreover, the dynamic performance of APSO based LQR tuning is characterized by a reduced overshoot and shorter delay time.

An algebraic approach for selecting the weighting matrices of LQR has been formulated based on the time domain requirements of the system to be controlled. Using the ARE, the coefficients of Q and R matrices are obtained as a direct function of system matrices and time domain parameters. The novelty of this approach is that a systematic framework for the choice of Q and R matrices of LQR has been formulated by incorporating both the quadratic cost function and time domain specifications. Simple mathematical expressions for selecting the weighting matrices which would satisfy the design criteria are obtained via ARE. The proposed methodology has been applied for trajectory tracking applications of magnetic levitation and torsional systems. Experiments are conducted to assess the performance of the algorithm and the improved trajectory tracking response of the torsional system suggest that the algebraic approach based weight selection algorithm can solve the manual tuning of LQR weight selection.
7.1 SCOPE FOR FUTURE WORK

Although the proposed algebraic approach based weight selection algorithm and APSO based LQR weight tuning algorithm solve the LQR weight optimization problems, these optimization methods can be extended for higher order systems with system uncertainty. Moreover, the performance of State Dependent Riccati Equation (SDRE) controller can be explored for tracking and stabilizing applications of under actuated systems with parameter uncertainty. Since SDRE Controller is a nonlinear controller, the robustness of the controller against the disturbance signals and parameter uncertainty can be investigated for improved tracking response. Similarly, the linear quadratic optimal control algorithms implemented for pendulum and magnetic suspension system can be extended to other under actuated systems such as ball and beam system and multi DoF torsion control.