Synopsis

Sliding-mode controllers, or SMCs, have immense potential for their robustness against inherent uncertainties and tackling nonlinear features that has been attracting many researchers to explore their applicability for electrical, electrohydraulic and electromechanical systems. The key to robustness is to design a system-specific control that would guide the terminal phase of the system trajectory to the demand point in the phase plane in a similar manner irrespective of the system features. From an initial point, the control drives the trajectory to this terminal-phase around a switching curve or the sliding surface. A phase plane is described either by the error in response with respect to the demand and the derivative of the error or by a switching function and its derivative, where a switching function is composed as a positively weighted sum of the error and its higher derivatives. Of course, the switching curves lie in the second and fourth quadrants and pass through the origin that represents also the demand point. In these quadrants, the error and the derivative remain out of phase. This guarantees reduction of the error magnitude till the trajectory reaches the origin. In order to achieve the sliding, the control requires switching the form at a high frequency so as to keep the trajectory attracted to the sliding surface. This high frequency switching of the input called chattering is an inherent feature of the SMC.

Relay-based power switching are routinely employed for electrical drives, for which interfacing of the SMC are relatively easy. Switching related inductive heating in the electrical circuit is easily managed by appropriate cooling arrangement. But special attention is necessary for electrohydraulic systems, especially for those possessing substantial nonlinearities in the cylinder friction and the flow characteristics in proportional valves. In a hydraulic cylinder or motor with standard seal material, this arises as a discontinuous jump in the static friction during motion onset or reversal. Existing applications of SMC for electrohydraulic systems mostly involve servovalves that do not possess large deadband typical of proportional valves. Due to the deadband, mentioned by Bessa et al. as a hard nonlinearity, flow fails to take off against control excitations within small thresholds around the null. When the system states pass through a hard zone, the switching of control forms could trigger output oscillation and even instabilities. For the wide range of applicability of electrohydraulic systems with
proportional valve and industry-grade cylinders, handling of hard nonlinearities within SMC framework for such systems indeed need more attention.

Electrohydraulic systems are well suited for bulk material handling and heavy-duty applications due to their high power density, fault tolerance and high speed of control response. These systems could often encounter dusty and harsh working conditions. Some instances are agricultural vehicles, forest harvesting manipulator and construction machineries. Apart from the cost benefits offered by proportional valves and industry-grade cylinders over their more sophisticated counterparts, namely servovalves and servo cylinders respectively, the sophisticated systems are more difficult to maintain in harsh environments for their higher oil filtration requirement. Therefore, from application viewpoint, a design that combines a rugged electrohydraulic system with a robust sliding-mode controller is quite motivating. The null leakage in a proportional valve can be less than that in a servovalve and in many cases intermittent control action away from the null is employed. If a good controller can provide comparable performance from both types of valves, the benefit of mitigating power waste during null operation could be quite rewarding. Prevailing energy-saving hydraulic systems are of relatively lower speed of 0.1Hz with either a fixed-speed variable-displacement pump with a passive closed-centre valve or a variable-speed fixed-displacement pump. Embedding an improved controller with a passive closed-centre valve could provide a servo-grade proportional valve leading to an energy-efficient solution at a faster speed of response.

The objective of the thesis is designing an SMC for a rugged electrohydraulic system. Suitable models for the dynamics of flow through a proportional valve and motion of a piston in a cylinder with high static friction have been employed. Required system characteristics for this purpose have been extracted from the manual of a proportional valve and the experimental results obtained in a laboratory set up. A compression spring has been used for externally loading the piston. The linear variation of load with piston displacement due to the spring compression is typical of many systems like swash-plate of a variable-displacement pump and motion simulator. While the comprehensive model has been used for performance simulation of the system, a simplified incompressible model has been adopted for the ease of developing the controller model. Such an implementation does not call for using an explicit observer and makes the on-line extraction of the voltage from the input-linearizing SMC variable quite easy. A detailed simulation study and experimental investigations have been carried out to arrive at the
desired controller through a detailed study of 1-SMC and 2-SMC. In order to resolve the voltage chattering problem, a PI controller has been used about the regulation demand. For tackling the hard nonlinearity, position-error dependent different biasing strategies have been investigated.