Abstract:

In recent times, incremental stability has been explored to address various challenges such as tracking, regulation, observer design, coordination, and synchronization. Contraction analysis, a powerful tool is typically employed to infer incremental stability for nonlinear systems. In contrast to conventional Lyapunov stability, contraction theory studies the convergence characteristics of trajectories with respect to each other instead of exclusively with respect to a specific equilibrium point. This property is exploited in the observer, controller design, and synchronization problems in several applications. In this thesis, we have used contraction analysis for observer and controller design for several classes of systems based on easily tractable matrix measures conditions. The work also introduces output feedback control based on an extended high-gain observer (HGO), ensuring the contraction of a singularly perturbed (SP) system's contraction. The standard contraction theory demands the dynamics to be sufficiently smooth. However, the smoothness assumption fails in many applications, such as switched and hybrid systems. There are very few existing literatures that considers this issue, and it lacks comprehensive coverage of switched dynamical systems. This thesis introduces contraction analysis tailored for switched interconnected systems and derives sufficient conditions to ensure incremental stability. The methodology incorporates matrix measure-based analysis and solution estimates of nonlinear dynamical systems. In the case of state-dependent switched systems, the key role of contraction theory lies in facilitating the regularization of the system by approximating it with a smooth dynamical system. This regularization process is essential for applying standard contraction results. The analytical framework is extended to more practical interconnected switched nonlinear systems in the presence of input. This has led to the introduction of the incremental ISS of the interconnected system. The small gain characterization of nonlinear systems connected in feedback plays a major role in interconnection. The analytical frameworks presented in the thesis cover that aspect as well. The results are derived for different classes of interconnection. The thesis also studies contraction of nonlinear switched systems based on time-dependent switching. The role of dwell time and average dwell time in time-dependent switched systems is discussed in detail. Sufficient conditions are derived for switched system in presence of mixed contracting and noncontracting modes, such that incremental stability of overall system is guaranteed. The incremental stability-based analysis and design are also extended to switching controllers, where switching is introduced in the system by virtue of controllers. At last, an interesting application in which harmonic suppression in switched mechanical systems is presented using contraction analysis.