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Output Feedback Switching Control of Systems with State and Control Constraints

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This thesis deals with switching control law for linear discrete-time systems with pointwise-in-time constraints on state and control. The purpose of switching control is to resolve a common conflict in the design : avoiding violation of specified constraints, while simultaneously meeting performance objectives such as fast response. Many different approaches that include switching control have been proposed for the analysis and design of control systems subject to constraints. However all state information is required since their law is based on a subset of state-space. In real systems, it is hard to get state information completely. In this respect, the purpose of this thesis is to derive switching control law, based on output feedback, for constrained systems.

Linear models play a vital role in control system design. Powerful design techniques are available synthesizing which achieve a variety of performance and robustness objectives. Treatment of systems with significant nonlinearities and the design objectives are needed.

In applications the design of feedback controllers is often complicated by the presence of physical constraints: saturating actuators, temperatures and working space limited by constructive restrictions, and so on. Violation of constraints leads to performance deterioration and even instability if not properly accounted for in the design procedure. Constraints render a control problem nonlinear even when the plant itself is linear.

In engineering practice, undesirable effects of constraints are often attacked by a combination of compromises such as: relaxation of performance objectives in the linear system design, restrictions on the class of inputs, use of more powerful actuators. These are not essentially as a solution to problem.

In this thesis a systematic control design methodology for linear discrete-time systems with state and control constraints is considered.

First, this thesis is concerned with characterizing initial states of unforced linear system whose subsequent motion satisfies a specified pointwise in time constraints. The set of such initial states is defined as the constrained positively invariant(CPI) set, and are based on the notion of state constrained set and positively invariant set. The state constrained set is the set of all state variables which satisfy the constraints. The positively invariant set is characterized by its property that keeping the state variables in its own region. The CPI set is the largest positively invariant set which is contained in the state constrained set. It is also shown that there exists maximal CPI set which is a CPI set and also contains any CPI sets. The necessary and sufficient condition for non-violation of constraints is the initial state of linear discrete-time system lies in the maximal CPI set. Such characterizations have important applications.

Secondly, this thesis is concerned with switching control, based on state feedback, as a design for constrained systems. Switching control is aim to overcome the common design dilemma associated with fixed controllers: achievement of high performance while maintaining a large region of safe attraction. The family of switched controllers is designed to have increasing levels of performance with the highest level controller being the desired controller. Lower level controllers sacrifice performance for improved safety : the capability of the corresponding closed-loop systems to avoid constraint violations resulting from larger sets of initial plant states. The notion of maximal CPI set is key factor for predicting safe operation. Supervisory logic selects the highest level controller that is safe for the current state of the plant and maximal CPI sets. It also initializes the controllers by solving some quadratic programming problem when they are newly selected. A key advantage of this approach is that compromises need not be made in the linear design process since avoiding violation of specified constraints is achieved additional logical structures. The effectiveness of this design methodology is illustrated in the simulation of a simple example. One of disadvantage is that complete measurements of plant state is needed due to switching concept based on some subset of state-space. In real systems, it is hard to get state information completely.

Thirdly, when states of a system are not available, there is a need for state estimators that yield estimates of states. This thesis is concerned with a Set-Valued observer(SVO) as state estimator. The SVO is constructed which recursively computes the set of possible states consistent with input and output measurements and plant dynamics. The set of possible states forms a polytope described by a collection of inequalities. The computational burden of a real time implementation is attenuated by solving several linear problem and removing redundant constraints. Generally, observer guarantees that the error in the estimate converges to zero asymptotically. However the relationship between the true state and the estimated state is not obtained exactly. The merit of using SVO is that the true state belongs to that set, that is, the region where the true state exists is obtained exactly, unless the effects of the errors in the modeling of plant dynamics. Furthermore, in the case of non-exogenous inputs, it is guaranteed that the estimated state converges to the true state in finite time. These merits play an important role in realization of control law used state-space especially. The effectiveness of SVO is illustrated in the simulation of several examples in the both case of non-exogenous and exogenous inputs.

Finally, this thesis considered deriving switching control law, based on output feedback, for constrained systems. In the output feedback case, the states of a system are not available. However switching control law requires the complete measurements of plant state due to its concept used state-space. This difficulties have not been handled by the switching control laws which were proposed in the literatures. The proposed switching control law applies the SVO as a state estimator. The family of switched controllers is designed to have increasing levels of performance with the highest level controller being the desired controller. Lower level controllers sacrifice performance for improved safety. Supervisory logic selects the highest level controller that is safe for the set of possible states of the plant provided by the SVO and maximal CPI sets. It also initializes the controllers by solving some quadratic programming problem when they are newly selected. The advantages of the proposed design methodology are illustrated in the simulation of the same example as state feedback.

The main result is to derive switching control law, based on output feedback, for constrained systems. The approach applies the SVO as a state estimator. The proposed switching control law assures convergence of the state and successive controller switching.