PASSIVITY AND TIME-SCALE DECOMPOSITION TECHNIQUES FOR NONLINEAR MULTI-AGENT COORDINATION

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ABSTRACT

Recent years have witnessed an increasing number of feedback applications in mobile sensor networks, cooperative robotics, and vehicle formations. An essential feature of these applications is using local feedback to achieve a prescribed group behavior. Group coordination and formation control designs are utilized in a wide range of applications including autonomous sampling networks, schooling and flocking in biological organisms, optimized sensor coverage, distributed computing, drag reduction, under-way replenishment operations, safety in adversarial environments, etc.

In this thesis, we pursue nonlinear control designs that achieve group coordination. We assume a bidirectional information flow between members, and study a class of feedback laws that are implementable with local information available to each member. We first review a unifying passivity framework for the group coordination problem in continuous-time. Then, we extend it to a class of sampled-data systems by exploiting the passivity properties of the underlying continuous-time system, and prove semiglobal asymptotic stability as the sampling period and a feedback gain are reduced. We next consider a gradient climbing problem where the objective is to steer a group of vehicles to the extrema of an unknown scalar field distribution while keeping a prescribed formation. We address this task by developing a scheme in which the leader performs extremum seeking for the minima or maxima of the field, and other vehicles follow according to passivity-based coordination rules. The extremum-seeking approach generates approximate gradients of the field locally by dithering sensor positions. We show that if there is sufficient time-scale separation between the fast dither and slow gradient motions of the leader vehicle, the followers only respond to the gradient motion, and filter out the dither component, while keeping the prescribed formation.

Another major research topic in large scale systems is obtaining computationally tractable reduced order models that allow efficient simulation and analysis in the presence of varying operation conditions, parameters, etc. In this thesis, we present a time-scale separation based model reduction technique for large scale interconnected systems. We show that a two time-scale behavior can be induced by the network topology if it exhibits densely-connected clusters with sparse links across them, and prove that the dense connections cause coherent behavior to emerge within the clusters in the fast time-scale. The clusters then behave as aggregate nodes that determine the dynamic behavior of the system in the slow time-scale. We develop a theoretical justification of the dense/sparse approach to model reduction by transforming the network model into a singularly perturbed form that makes the time-scale separation explicit. This dense/sparse approach to area aggregation complements the strong/weak approach reported in the literature, and is applicable to a number of natural and technological networks of current interest. A major advantage of this time-scale approach to aggregation is its appeal to physical intuition, which can be lost in reduced models constructed merely for algebraic or numerical efficiency.