MULTI-AGENT COLLECTIVE BEHAVIORS ANALYSIS AND APPLICATIONS IN COMPLEX NETWORKS AND SYSTEMS

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Abstract

Cooperative and collective behaviors in networks of multiple autonomous agents have received considerable attention in recent years due to the growing interest in understanding intriguing animal group behaviors, such as flocking and swarming, and also due to their emerging broad applications in sensor networks, UAV (Unmanned Air Vehicles) formations, robotic teams, to name just a few. To coordinate with other agents in a network, every agent needs to share information with its adjacent peers so that all can agree on a common goal of interest. Recently, some progress has been made in analyzing collective behaviors in dynamical networks for which some closely related focal topics are synchronization, consensus, swarming and flocking.

In this thesis, the multi-agent collective behaviors (specifically, synchronization, consensus, swarming, and flocking) and some of their potential applications are investigated. In particular, following issues are studied in detail: (a) first-order consensus in multi-agent systems with nonlinear dynamics; (b) second-order consensus in multi-agent systems with time delays and linear or nonlinear dynamics; (c) higher-order consensus in linear multi-agent dynamical systems; (d) stability analysis of a swarming behavioral model with hybrid nonlinear profiles; (e) distributed leader-follower flocking control for multi-agent dynamical systems with time-varying velocities; (f) adaptive and pinning network controls in complex dynamical systems; (g) applications in estimating uncertain delayed genetic regulatory networks and distributed consensus filtering in sensor networks.

The main contributions of this thesis are summarized as follows: (a) a generalized algebraic connectivity framework is proposed to describe the consensus ability in multi-agent systems; (b) some necessary and sufficient conditions for second-order consensus in linear multi-agent dynamical systems are derived which show that both the real and imaginary parts of the eigenvalues of the Laplacian matrix of the corresponding network play key roles in reaching consensus and the allowable maximum communication delay is explicitly calculated; (c) some necessary and sufficient conditions are derived for higher-order consensus and it is theoretically proved that for the mth-order consensus, there are at most $\llcorner \frac{m+1}{2} \lrcorner$ disconnected stable and unstable consensus regions; (d) stability analysis of a swarming behavioral model with stochastic noise, switching nonlinear profiles, time-varying communication topologies, and unbounded repulsive interactions, is investigated; (e) a distributed leader-follower flocking algorithm for multi-agent dynamical systems with time-varying velocities is developed, where each informed agent only needs partial information about the leader; (f) an effective distributed adaptive strategy to tune the coupling weights of a network is designed based on local information of nodes' dynamics, and it is found that synchronization can be reached if the subgraph consisting of the edges and nodes corresponding to the updated coupling weights contains a spanning tree; in addition, some new pinning schemes for complex networks are designed; (g) uncertain delayed genetic regulatory networks are investigated from an adaptive filtering approach based on an adaptive synchronization setting, where the designed adaptive laws are independent of the unknown system states and parameters, requiring only the output and the structure of the underlying network; furthermore, a new type of distributed consensus filters is designed, where each sensor can communicate with the neighboring sensors and only a small fraction of sensors need to measure some partial target information.

This thesis provides a thorough review of the state-of-the-art progress of the field and summarizes the author's research work and academic contributions completed during the PhD studies at the City University of Hong Kong.

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