Chapter 9

Distributed Adaptive Control for Multi-Agent Systems with Pseudo Higher Order Neural Net

Abhijit Das
Automation and Robotics Research Institute, USA

Frank Lewis
Automation and Robotics Research Institute, USA

ABSTRACT

The idea of using multi-agent systems is becoming more popular every day. It not only saves time and resources but also eliminates much of the human workload. These ideas are especially effective in the combat zone, where multiple unmanned aerial vehicles can achieve simultaneous objectives or targets. The evolution of distributed control started with a simple integrator systems, and then different control methodologies have been adopted for more and more complex nonlinear systems. In addition, from a practical standpoint, the dynamics of the agents involved in networked control architecture might not be identical. Therefore, an ideal distributed control should accommodate multiple agents that are nonlinear systems associated with unknown dynamics. In this chapter, a distributed control methodology is presented where nonidentical nonlinear agents communicate among themselves following directed graph topology. In addition, the nonlinear dynamics are considered unknown. While the pinning control strategy has been adopted to distribute the input command among the agents, a Pseudo Higher Order Neural Net (PHONN)-based identification strategy is introduced for identifying the unknown dynamics. These two strategies are combined beautifully so that the stability of the system is assured even with minimum interaction among the agents. A detailed stability analysis is presented based on the Lyapunov theory, and a simulation study is performed to verify the theoretical claims.

INTRODUCTION

Coordination and consensus of distributed groups of agents is inspired by naturally occurring phenomena such as flocking in birds, swarms in insects, circadian rhythms in nature, synchronization and phase transitions in physical and chemical systems, and the laws of thermodynamics (Hui & Haddad, 2008). Early work has been done in the control systems community by Fax & Murray (2004), Jadbabaie, Lin, and Morse (2003), Olfati-Saber and Murray (2004), Ren and Beard (2005), and Tsitsiklis (1984), which by now are...
well known. Consensus has been studied for systems on communication graphs with fixed or varying topologies and communication delays. The average consensus problem has garnered much interest. Synchronization to time-varying trajectories has been studied based on physical or natural systems by Chopra and Spong (2009), Kuramoto (1975), Strogatz (2000), and Vicsek, Czirok, Jacob, Cohen, and Schochet (1995). Synchronization of nonlinear passive dynamic systems has been studied by Chopra and Spong (2006). Consensus using nonlinear protocols has been considered there and in Hui and Haddad (2008).

Convergence of consensus to a virtual leader or header node has been studied in Jadbabaie et al. (2003) and Jiang and Baras (2009). Dynamic consensus for tracking of time-varying signals has been presented in Spanos, Olfati-Saber, and Murray (2005). Recently, the pinning control has been introduced for synchronization control of coupled complex dynamical systems (Li, Wang, & Chen, 2004; Li, Duan, & Chen, 2009; Lu & Chen, 2005; Wang & Chen, 2002). Pinning control is a powerful technique that allows controlled synchronization of interconnected dynamic systems by adding a control or leader node that is connected (pinned) into a small percentage of nodes in the network. These pinned or controlled nodes view the control node simply as another neighbor, and consider the control node’s state value in computing their local protocols. Analysis shows that all nodes converge to the state of the control node, which may be time varying. Analysis has been done using Lyapunov techniques by assuming either a Jacobian linearization of the nonlinear node dynamics or a Lipschitz condition. A related idea is soft control (Han, Li, & Guo, 2006) where a shill node moves through the network, and is perceived by existing nodes simply as another neighbor for purposes of computation of their own averaging protocols. Proper placement and motion of the shill agent results in consensus to the state of the shill.

Consensus and collective motion of distributed agents has been analyzed using the theory of graphs and/or Markov processes. Recent publications allow analysis using traditional control theory notions including matrix analysis, Lyapunov theory, etc., upon the introduction of certain key definitions including irreducibility, M-matrices, Frobenius form, special Lyapunov forms, etc. Notable are the books by Qu (2009) and Wu (2007). Such techniques allow one to bring in the machinery of matrix analysis (Bernstein, 2005). Instrumental in this analysis are the techniques employed in Kho, Xie, and Man, 2012).

Distributed multiagent systems with unknown nonlinear dynamics and disturbances were studied in Hou, Cheng, and Tan (2009) where distributed adaptive controllers were designed to achieve robust consensus. That treatment assumed undirected graphs and solved the consensus problem, that is, the nodes reach a steady-state consensus that depends on the initial conditions. Expressions for the consensus value were not given.

The study of control protocols on digraphs is significantly more involved than their study on undirected graphs, where the graph Laplacian potential can be taken as a Lyapunov function. In this research, we present a Lyapunov-based technique embedded with PHONN for design of protocols for robust synchronization to tracking of a leader or control node. Design techniques are developed for general digraphs. The leader has unknown nonlinear dynamics, and the nodes have unknown, non-identical, nonlinear dynamics and disturbances. Suitable control protocols are derived using a Lyapunov function that is carefully crafted to depend on a special local synchronization error that can be computed in a distributed fashion. The control laws thus derived are distributed in nature and can be implemented locally by each node. They consist of a linear protocol plus a nonlinear adaptive learning component, which is derived from HONN like neural net (PHONN). These protocols are robust to uncertain distur-
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