ABSTRACT

A multi-agent system comprises a group of dynamical systems, with an individual system being referred to as an *agent*. These agents work cooperatively via appropriate communication links to achieve some specific collective objectives such as consensus, formation, and synchronization. When the dynamics of an agent involve differential and algebraic equations, it can be represented as a descriptor system (DS): $E\dot{x}(t) = Ax(t) + Bu(t)$, where the matrix E is a *singular* matrix. Many physical systems with *state constraints* (represented using algebraic equations) are often suitably modeled as descriptor systems. The examples of such systems are robotics, power networks, biological systems, and cyber-physical systems. Some of the characteristics that make DSs different from ordinary state-space systems are: the state response of a DS may not exist if it is not *regular*, and could be *impulsive* for non-smoothness control input and/or inconsistent initial conditions. The presence of impulse in the system response may damage or saturate the physical components, and hence, it should be eliminated. A network of such descriptor systems is referred to as a *descriptor multi-agent system* (DMAS). In a multi-agent setting, the distributed feedback control architecture is preferred in comparison to centralized feedback control due to several advantages, such as a reduction in the number of communication channels and avoiding single-point failure. In a distributed feedback control, each agent uses the state or output information only from the neighboring agents. In this regard, this thesis considers the design of a distributed control architecture for a DMAS to address the leader-follower synchronization problem and *eliminate the impulsive response* in the closed-loop network. In *leader-follower synchronization*, a leader agent generates a desired reference trajectory, and a control law is designed to ensure that the states of the follower agents synchronize with the states of the leader agent.

In particular, the initial work of this thesis focuses on the asymptotic convergence of leader-follower agents while also addressing the elimination of impulsive responses in the closed-loop system. To achieve this control objective, a distributed static state feedback control law is proposed, where the closed-loop DMAS is made impulse-free through a feedback gain matrix. Furthermore, the system is transformed into a set of decoupled descriptor systems using the property of the network graph Laplacian matrix. Then, by performing appropriate decomposition of the transformed descriptor systems, the synchronization objective is achieved by stabilizing a set of ordinary state space systems through solving an Algebraic Riccati Equation. Next, we consider another problem where the states of follower agents synchronize with the states of leader agents satisfying a pre-

specified *minimum decay rate*, which helps to regulate the synchronization speed. Moreover, the impulse-free closed-loop response is also guaranteed. By performing a sequence of system transformations through orthogonal matrices and using a *parametric robust control* framework, the synchronization problem is addressed. The corresponding gain parameters are computed by solving a linear matrix constraint problem and using the largest eigenvalue of the network Laplacian matrix. These control schemes are developed under the assumption that all states are measurable, which is then used to design a static state feedback control. Nevertheless, the states can not always be measurable in practice due to the lack of sensors or cost considerations. Therefore, the subsequent work of the thesis focuses on designing a *local observer-distributed control* scheme for DMAS, allowing the agents interaction to be cooperative and antagonistic. For this, a *reduced-order observer* of order $n_0 = \text{rank}(E)$ is proposed to estimate the states of all the agents in the network. The proposed control architecture comprises an *output-based* local control law to eliminate impulsive responses and an *estimated state-based distributed feedback law* to achieve the synchronization objective. The feedback control algorithm provides flexibility to design controller and observer gain matrices independently, and hence, the standard *separation principle* holds. Moreover, considering only cooperative interactions among the agents, the proposed observer-based control law is extended to achieve synchronization for an uncertain network graph. The associated feedback gain parameters are designed using system transformation through orthogonal matrices only. Therefore, the developed feedback control algorithm is numerically efficient. The effectiveness of developed algorithms is demonstrated with numerical examples and practical example such as microgrids.