Paper Review: Information Consensus in Multivehicle Cooperative Control

Tomoki Koike

***Abstract*—We will analyze and dissect a paper by Wei Ren, Randal W. Beard, and Ella M. Atkins[1]. The main objective of this paper is to provide a overview of information consensus in multivehicle cooperation control. The paper seeks to investigate possible consensus algorithms that enable a coordinated control of autonomous vehicles that have the potential to conduct tasks such as space-based interferometers, surveillance, sensor networks, etc.**

***Index Terms*—Consensus Algorithms; Cooperative Control; Graph Theory; Topology; directed graph; undirected graph**

I. Introduction and Motivation

This paper discusses the basic idea of consensus algorithms to derived from a communication network among vehicles. The updating of information states between each node with communicating neighbors is probed with the graph theory to clarify the derivation and foundations of consensus algorithm. Furthermore, the analysis extends to the convergence and the equilibrium state of time-invariant communication networks. In contrast to time-invariant systems, they also explain the characteristics of dynamic networks. The non-linearity of multi-agent systems are investigated using the Lyapunov analysis and the discussion moves onto the synthesis and extensions of the consensus algorithms for further studies.

This paper is written in the hopes of setting the basis for consensus algorithms and stimulating further research of the topic to enable effective and efficient use of cooperative multi-agent controls in modern technology.

II. Problem Formulation

In the first section, the paper formulates the basis for consensus algorithms using scalar information update of multiagent systems modeled as a first order differential equation. The communication updates for each node varies depending on the topology of the network. There is a common consensus algorithm that drives the system to convergence regardless of the topology. The algorithm described in the paper is as follows.

$$\dot{x}_i(t) = -\sum_{j=1}^{n} a_{ij}(t)(x_i(t) - x_j(t)), \qquad i = 1, ..., n.$$

The main question addressed is how the information state for all vehicles converge with this algorithm. It posits that for a fixed topology with time-invariant weights of the consensus algorithm there exits a common converging value determined by a convex combination of the initial states of the system.

A key point they mention for a time invariant system is that it converges if and only if the directed communication topology includes a root directed spanning tree or the undirected communication topology is connected. Furthermore, for a fixed topology an equilibrium state, or in other words, an average consensus is achieved if and only if he directed communication topology is both strongly connected and balanced. While for a undirected communication, average consensus is obtained if and only if it connected.

All of what have been discussed were based on the assumption of a time invariant and fixed topology system. However, with the example of a rendezvous of multiagents, this may not be possible due to the disturbances from the environmental changes. Thus, the paper analyzes the conditions for a dynamic communication topology or switching topology where the network changes by time. For a switching topology, algebraic graph theory is used to explain the algebraic structure of corresponding matrices such as the transition matrix corresponding to each Laplacian matrix. The transition matrix for each switching instant turns out to be a row stochastic matrix, and therefore, the convergence analysis for this system involves a infinite product of stochastic matrices. Often the stochastic structure of multiagent systems involve nonlinear dynamics with more complexity, and to address this the paper suggests the use of the Lyapunov analysis for nonlinearity. Also for the updates of information states the paper postulates the use of asynchronous communication frameworks which is also a large field that is currently researched.

III. Main Results

As a result of the theories that the paper has gone over in the first 7 pages, in the last few pages they discuss the synthesis and extensions of consensus algorithms. One example is a swarm of UAVs or micro-air vehicle which involve consensus synthesis. The consensus of such system requires to solve a fastest distributed linear averaging (FDLA) problem which boils down to a solvable semi-definite program. Moreover, one approach to tackle dynamic disturbances of flying mutliagent systems is to synthesize a decentralized state feedback control law for the consensus of a closed-loop system. This method is proposed to achieve not only consensus but optimal performance while attenuating disturbance.

Next, the paper discusses the use of a consensus manager that guarantees synchronous arrivals for rendezvous applications. Other interesting application topics were formation stabilization and formation maneuvering and flocking. For the former topic, they mention how for a decentralized formation stabilization problem the formations require to be negotiated for each agent and an information flow filter could be used to improve stability margins and formation accuracy. For the latter topic, pertains to decentralized formation maneuvers and involves the formation controls with environmental variables and feedback controls to stabilize the dynamics.

The paper fulfills its objective of showing applications and possible interest of research in the field of consensus algorithms by serving as a overview of the topic as well as introducing more in-depth applications of the study.

IV. Your Ideas of Further Improvements

I have personally been involved in research of path planning and the notions of the graph theory and consensus algorithms seemed to be a protocol to further polish existing path planning algorithms. Namely, RRT and RRT* algorithms involve the use of randomly generated nodes and path optimizations by connected edges based on heuristic approach. Due to the random nature of RRT the algorithm has its pros and cons depending on the assumptions and requirements for object avoidance. From this reading I have gained interest in investigating if it is possible to incorporate consensus algorithms to improve it by considering the RRT framework as one communication network consisting of a fixed but expanding topology.

References

[1] Wei Ren, Randal W. Beard, and Ella M. Atkins. Information consensus in multivehicle cooperative control. *IEEE Control Systems Magazine*, 2007.