Research Statement

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My research focuses on distributed estimation and cooperative control, graph theory, and multiplex networks with applications to multiagent systems, robotics, and dynamic data driven application systems. In these research areas, I have co-authored over 15 peer-reviewed journal and conference publications; gave invited talks; implemented algorithms and performed experiments on a wide array of ground and aerial robots (for examples, Qbot 2, Khepera IV, Parrot AR Drone 2.0, and Crazyflie). I believe theoretical and experimental research are complement components of each other in contribution to emerging technologies. Specifically, I personally suppose a control system researcher should consider a problem from both physical and mathematical views, since physics can play the role as the inspirational factor for formulating and understanding problems as well as generating new ideas while mathematics is the tool to execute those ideas. For that reason, I always enhance my skills in both theoretical and applied directions. This understanding has formed the characteristics of my research. In what follows, I first give an overview of my previous and current research background and then dive into details.

Research Background

My research aims to address challenges in multiagent systems with distributed estimation and cooperative control, graph theory, and multiplex networks. It is interesting to observe the cooperative behaviors of animals in nature such as ants working together to find and transport food back to their nest; birds flying in V-shape formation to reduce the drag forces between each other and save energy during a long flight; or some fish swimming in schools not only to increase their sensing capability but also to confuse their enemy, and hence, boost the survival chance. These advantages of group behaviors together with the advancements in technology over the past decades, which makes deploying multiple robots become feasible, are the main motivation for developing algorithms and applications for a group of robots (i.e., multiagent systems) so that they can communicate, collaborate, and coordinate with one another for the purpose of achieving a global task. Multiagent systems are also required to operate robustly under adverse conditions and dynamic environment along with a distributed manner. In particular, my research provides: (i) situation awareness with cooperative sensing in sensor network; (ii) spatial and temporal control over multiagent systems (for example, formation control for a group of mobile robots with multiplex network); (iii) a better understanding on the interactions between agents in multiagent systems from a new graph theory perspective; and (iv) real-world applications.

Previous and Current Research

As a Ph.D candidate, I have been participating in many externally funded research projects under the supervision of Dr. Tansel Yucelen. In this section, I give a concise summary of my research contributions by projects as listed in the previous section.

In the projects "Autonomous Multivehicle Systems for Real-Time Situational Awareness in Adverse Environments" (from 2015 to 2016, sponsored by Oak Ridge Associated Universities) and "System-Theoretic Principles and Decentralized Sensor Network and Control Algorithms for Dynamic Data-Driven Situational Awareness and Response" (from 2017 to 2018, sponsored by Air Force Office of Scientific Research), I have worked with Dr. Yucelen (Missouri University of Science and Technology and later moved to University of South Florida in 2016) and Dr. Sarangapani Jagannathan (Missouri University of Science and Technology) on developing a decentralized information fusion framework for situation awareness in the presence of heterogeneity resulting from the sensing capabilities of nodes and nonidentical sensor types with complementary properties distributed over the network. Specifically, we consider a heterogeneous sensor network where each node can communicate with its neighbors, and at each time instant if a node can sense a process of interest (or a target), then it is called "active"; otherwise, it is "passive". During a mission, a node can change from passive to active and vice versa as illustrated in Figure 1. The framework utilizes the active-passive dynamic consensus filter together with local observers to distribute the information from active nodes to the whole network so that each node, whether passive or active, can estimate both the input and state of the process of interest.

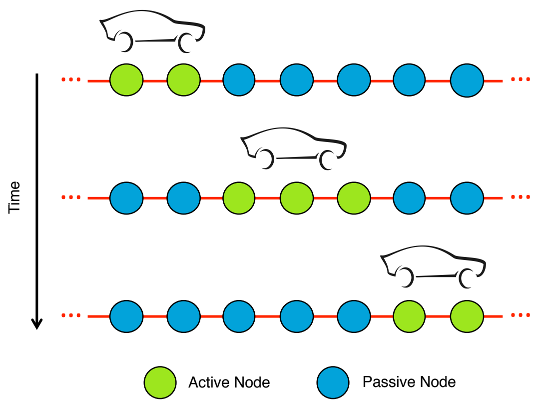

Figure 1: An illustration of the distributed dynamic information fusion scenario in a sensor network with time-varying active and passive node roles (lines and circles respectively denote communication links and nodes).

Spatial and temporal control over multiagent systems are studied during the time I worked at The United States Air Force Summer Faculty and Student Fellowship Program at the Munitions Directorate in Eglin, Florida in Summer 2015, and in the project "Multiagent Coordination over Prescribed Time Intervals: System-Theoretic Foundations and Distributed Control" (from 2017 to 2018, sponsored by Army Research Office), which I collaborate with Dr. Yucelen and Dr. Ehsan Arabi (University of South Florida and moved to University of Michigan in 2019). Specifically, multiplex information networks as applied to, but not limited to, formation control is the main theme of my doctoral research. While current methodologies for multiagent systems are designed based on a single layer information exchange rule, which leads to an overall system having fixed spatial properties (e.g., fixed formation size and orientation), multiplex information networks utilize multiple layers of consensus to manage and control spatial properties of multiagent systems in a distributed manner and allow them to accomplish complex operations. An experimental illustration of the methodology is available at `https://youtu.be/yhLVblWIA_4` where a group of robots forms and maintains a V-shape formation, tracks a dynamics target, avoids collision, and is manipulated to pass through a narrow passage in a distributed manner; that is, information such as position of the target, the desired scaling factor and rotation angle of the formation is only available to a leader robot through communicating with the operator. In addition, the project "Multiagent Coordination over Prescribed Time Intervals: System-Theoretic Foundations and Distributed Control" provides a temporal control over multiagent systems. Particularly, we develop and generalize distributed control algorithms for multiagent systems to achieve a-priori given, user-defined finite time convergence to a dynamic target. The baseline of this research is to use time transformation method to transform the system from the prescribed time interval $t \in [0, T)$ to an equivalent system over the stretched infinite-time interval $s \in [0, \infty)$ for analysis purposes. An application and illustration of this methodology is cooperative engagement in finite time, which can be found at `https://youtu.be/09fAeJzax9Y`. In the experiment, four ground robots communicate with each other according to a path graph and split into two small groups in order to engage two dynamic targets at a user-defined time.

In a recent research, we modify the Laplacian matrix in order to achieve desired behaviors for multiagent systems. This research defines a more general version for Laplacian matrix and reveals a better understanding on the interactions between agents in multiagent systems. It is a novel and promised distributed algorithm for generating a broad range of complex cooperative behavior in multiagent systems. The detail of this research will be publicly available in the near future.

In this last year as a doctoral student, I am also working on application projects such as "Energy Efficient Flight of Cruise Missiles through CFD Analysis and Feedback Control" (with Dr. Yucelen and Dr. Tejada at University of South Florida, from 2018 to 2019, and sponsored by Lockheed Martin) and "Dolittle/Sofwerx Research Program" (with Dr. Yucelen and Dr. Chellappan at University of South Florida, from 2018 to 2019, sponsored by Dolittle/Sofwerx + Florida High Tech Corridor). Specifically, in the latter project, I am investigating and implementing vision-based formation control and visual odometry on ground robots. These applications open up multiple directions for my future research including controlling and navigating multiagent systems in GPS-denied areas and information fusion for visual odometry and inertial odometry.