MAE-247. Cooperative Control of Multi-agent Systems
UCSD Mechanical and Aerospace Engineering, Spring 2023

Instructor: Sonia Martínez, FAH 3302, 858-822-4243, `soniamd@ucsd.edu`

Course description: This course provides an introduction to the modeling, analysis and design of the cooperative control systems. Topics include continuous-time and discrete-time evolution models, distributed algorithms, distributed linear iterations, proximity graphs, geometric optimization, invariance principles and coordination algorithms for agent aggregation, deployment, flocking, formation control, and consensus. The tools of the course will be presented through application settings such as robotic, sensor, power, transportation, social, computer, and natural networks. These examples, and many others, point to the scientific problem of how to design and model interactions so that the behavior of these complex systems can be predicted.

Prerequisites: Background knowledge of linear algebra, ODEs, dynamical systems, mathematical analysis, and mathematical reasoning. Familiarity with a simulation software or programming language.

Teaching assistant: Parth Paritosh `pparitos at ucsd dot edu`

Office hours: Instructor's: Tuesdays from 3:45pm to 4:45pm, place TBA Parth's: TBA

Lecture time and place: Tue and Thu: 9:30am – 10:50am, WLH 2207

Textbook and course material: The textbook is a collection of lecture notes developed by the instructor in collaboration with Professors Francesco Bullo and Jorge Cortés. Copies of the textbook are available in `http://www.coordinationbook.info/` Lecture notes will be provided in class. Occasionally, material from other sources will be taken, as referred to in these notes.

List of topics: The topics that will be covered in the course include the following (time permitting):

Part I
- Introduction: what are multi-agent systems?
- Linear algebra
- Graph theory
- Linear iterations and agreement
- Laplacian consensus, distributed optimization, formation control, distributed estimation, virus propagation

Part II
- Distributed algorithms on networks of processors
- Proximity graphs
- Distributed algorithms on robotic networks
- Connectivity maintenance and rendezvous for multi-robot systems
- Deployment for task assignment

Assignments: The class will be evaluated based on homework and a final project presentation (some exercises require mathematical proof development). There will approximately be a set of homework problems per week (mostly from the main text). Homework will be collected on Fridays. No late homework will be accepted with the exception of one assignment.

Student projects: Each student will choose a topic among the following categories and will either present an in-depth analysis of a paper in the chosen category (with a simulation of the algorithms in the paper) or develop a project on their own. All projects are to be presented in person in class during week 9 and week

10 of the course, (maybe extending to the final exam time) and all students are required to attend all others' presentations. Students will have to let the instructors know of their choice by the end of week 5 of the course. Possible project topics are the following:

1. Agreement and consensus algorithms,
2. Motion patterns and multi-robot synchronization,
3. Network controllability and observability,
4. Distributed Kalman filtering, distributed estimation, distributed map building
5. Game theory and cooperative control,
6. Opinion dynamics in large networked systems,
7. Distributed operation of cyber-physical networks,
8. Privacy and resilience in multi-agent systems,
9. Distributed learning in multi-agent systems,
10. Distributed reinforcement learning,
11. Distributed data-driven control

Students are encouraged to choose a project that is relevant to their own area of research. A list of papers in these categories will be made available shortly so students can choose among them.

Grading: Your grade will tentatively be calculated as follows:

- Homework and class participation: 70%
- Final project: 30%

Collaboration policy: You are encouraged to work with other students on your assignments, and to help other students complete their assignments, provided that you comply with the following conditions:

1. Honest representation: The material you turn in for course credit must be a fair representation of your work. You are responsible for understanding and being able to explain and duplicate the work you submit.
2. Active involvement: You must ensure that you are an active participant in all collaborations, and are not merely dividing up the work or following along while another student does the work. For example, copying another student's work without actively being involved in deriving the solution is strictly prohibited.
3. Work individually or in small groups: Working in groups of more than **three** people is discouraged because it limits the amount of participation by each member of the group. In your homework solutions please indicate the names of the people you collaborated with.
4. Give help appropriately: When helping someone, it is important not to simply give them a solution, because then they may not understand it fully and will not be able to solve a similar problem next time. It's always important to take the time to help someone think through the problem and develop the solution. Often, this can be accomplished by asking them a series of leading questions.
5. If in doubt, ask your instructor: Be sure to ask in advance if you have any doubts about whether a certain type of collaboration is acceptable.

Class participation: It is very much encouraged (and expected) that students will actively participate in the classroom asking questions or for clarification. Students may be asked to solve problems sporadically during the lecture.

Course website: A main external website will be at `http://muro.ucsd.edu/sonia/teaching/`; however, the website that will mainly be maintained is at `canvas.ucsd.edu`.

Academic honesty: No form of academic dishonesty will be tolerated. For a definition of academic dishonesty and its consequences, refer to the UCSD website `http://academicintegrity.ucsd.edu`