**Syllabus**

**ENME 808T: Network Control Systems**
**Fall 2019**

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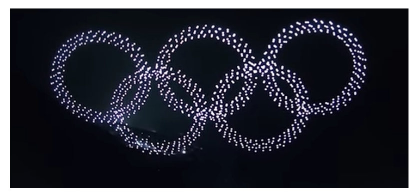
TA: TBD

*A network control system consists of dynamical units called agents that interact over a signal-exchange network for its coordinated operation and behavior.*





**Course Description:** With the advent of the internet and increasingly more powerful and inexpensive computing resources, network control systems have become a focus in the research community. Providing advantages with respect to robustness, complimentary capabilities, and task parallelization, network control systems have found applications in various domains including distributed sensing, power grids, and robotics.

In this course, a graph theoretic approach will taken to analyze and design network control systems. The following topics will be covered:

1. Modeling Networks (Graphs: geometric, random, state-dependent, time-varying)
2. Introduction to Algebraic Graph Theory
3. Controllability and Stability Properties of Network Control Systems
4. Sensor Networks, Mobile Robot Networks, Formation Control
5. Applications of Network Control Systems and Research Frontier

**Lecture Time and Place:** Mondays and Wednesdays from 3:30-4:45 pm in EGR 3114 (Martin Hall)

**Office Hours:** Wednesdays 1-3pm or by appointment.

**Course Prerequisites:** No formal prerequisites, but a background in linear algebra, linear control systems, and differential equations will help significantly.

**Textbook:**

- Graph Theoretic Methods in Multiagent Networks, by M. Mesbahi and M. Egerstedt, Princeton University Press, 2010. (See `http://press.princeton.edu/titles/9230.html`.)

**Supplemental Reading:**

- Distributed Control of Robotic Networks, by F. Bullo, J. Cortes, and S. Martinez, Princeton, 2009.
- Passivity-Based-Control and Estimation in Networked Robotics, by T. Hatanaka, N. Chopra, M. Fujita, and M.W. Spong, Springer, 2015.
- Algebraic Graph Theory, by C. Godsil and G. Royle, Springer, 2001.
- Networked Embedded Sensing and Control, edited by P. J. Antsaklis and P. Tabuada, Springer 2006.

**Workload:**

- **Homework (40%):** There will be five homework sets in total.
  - The first four homework sets will constitute 5% of the total grade each (total of %20), consisting of a combination of theoretical exercises and programming assignments in MATLAB.
  - The last homework set will be project-based, and includes a simulation component as well as a remote-access real multi-robot experiment implementation component using the Georgia Tech Robotarium (`www.robotarium.org`), and will constitute 20% of the total grade.
- **Midterm and Final (60%):** The midterm (20%) and final exam (40%) will be cumulative and cover all the material presented in class. They will be closed-book, closed-notes, closed-calculator.

**Academic Integrity:** You are encouraged to work together to learn the course material, including discussing homework assignments and preparing for exams with your peers. However, you must turn in your own work. It is considered cheating if a student turns in other than their own work (this includes but not limited to homework, exams, schematics, and figures). If a student is caught for cheating or facilitating cheating, they will be referred to the Office of Student Conduct.

The University of Maryland, College Park has a nationally recognized Code of Academic Integrity, administered by the Student Honor Council. This Code sets standards for academic integrity at Maryland for all undergraduate and graduate students. As a student you are responsible for upholding these standards for this course. It is very important for you to be aware of the consequences of cheating, fabrication, facilitation, and plagiarism. For more information on the Code of Academic Integrity or the Student Honor Council, please visit `http://www.shc.umd.edu`.

## Tentative Schedule (Subject to Change)

| Date | Lecture subject | Reading/Homework |
|---|---|---|
| Aug. 26 | What are networked control systems?<br>Rendezvous: a canonical problem | §1 |
| | **GRAPH-BASED NETWORK MODELS** | |
| Aug. 28 | Graph theory basics | §2 |
| Sep. 2 | **Labor Day – No Class** | |
| Sep. 4 | Algebraic and spectral graph theory | §2 |
| Sep. 9 | Connectivity, Cheeger's inequality, proximity graphs | §2 |
| | **THE AGREEMENT PROTOCOL: STATIC CASE** | |
| Sep. 11 | Decentralized agreements: consensus equation (static case) | §3 |
| Sep. 16 | Disagreement vectors | §3 |
| Sep. 18 | Average consensus, directed networks | §3, HW1 (graph theory) |
| Sep. 23 | Leader networks and distributed estimation | |
| Sep. 25 | Discrete time consensus | §3 |
| | **THE AGREEMENT PROTOCOL: DYNAMIC CASE** | |
| Sep. 30 | Switched networks | §4 |
| Oct. 2 | Lyapunov–based stability | §4 |
| Oct. 7 | Consensus equation: Dynamic case | §4, 7 |
| Oct. 9 | Weighted protocols, energy-based design,<br>connectivity maintenance | §6, HW2 (static consensus) |
| Oct. 14 | Biological models: flocking and swarming<br>Alignment and Kuramoto's coupled oscillators | |
| Oct. 16 | Review | |
| Oct. 21 | **MIDTERM** | |
| | **MULTI-AGENT ROBOTICS** | |
| Oct. 23 | Formations | §6 |
| Oct. 28 | Graph rigidity and persistence | §6 |
| Oct. 30 | Formation control and design choices | §6, HW3 (dynamic consensus) |
| Nov. 4 | Leader–follower networks | §10 |
| Nov. 6 | Network controllability and network feedback | §10 |
| Nov. 11 | Distributed optimal control | §10 |
| Nov. 13 | Project briefing | HW4 (formation control) |
| Nov. 18 | Human–swarm interactions | |
| | **MOBILE SENSOR & COMMUNICATION NETWORKS** | |
| Nov. 20 | Sensor networks, Gabriel and Voronoi graphs | §7 |
| Nov. 25 | Locational Costs, Coverage Control | §7 |
| Nov. 27 | **Thanksgiving Break – No Class** | |
| Dec. 2 | Communication models, random graphs, random consensus | §5 |
| Dec. 4 | Review, At the research frontier, National Robotics Initiative 2.0 | HW5 (Multi-Robot Experiment) |
| Dec. 9 | **Project presentations** | |
| Dec. ?? | **FINAL EXAM** | |