Information Flow in Cooperative Control of Multi-Vehicle Systems

http://www.cds.caltech.edu/~murray/projects/afosr01-coop

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Project Goals

- Develop theory for integration of information flow into control analysis and design for cooperative tasks of multi-vehicle systems
- Build on tools from control theory, dynamical systems, and graph theory to develop algorithms for analyzing and designing information flow
- Apply results to real-time, distributed control on Caltech multi-vehicle, wireless testbed (DURIP)

Project overview

This project is focused on developing the underlying theory required to achieve integration of information flow into control analysis and design for cooperative tasks of multi-vehicle systems. By making use of tools from control theory, dynamical systems, and graph theory, we are developing a framework for analyzing the effects of information and sensor topology on feedback systems and developing tools for designing information flow and control algorithms that build on this framework. We are applying these ideas to several test problems involving real-time, distributed control of a set of multiple vehicles performing cooperative tasks. In addition to computational exploration through simulation, we plan to implement our algorithms on a multi-vehicle, wireless testbed for networked control, communications, and computing that is being developed at Caltech.

Related Projects:

- Multi-Vehicle Wireless Testbed for Networked Control, Communications and Computing (DURIP)
- High-Confidence Reconfigurable Distributed Control (DARPA SEC)
- Cooperative Control of Distributed Autonomous Vehicles in Adversarial Environments (AFOSR MURI)
- Human Centered, Variable Initiative Control of Complex Automa-Teams (DARPA MICA)

More information on this project is available on the project web page:

http://www.cds.caltech.edu/~murray/projects/afosr01-coop

Information Flow in Cooperative Control of Multi-Vehicle Systems

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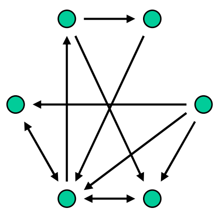
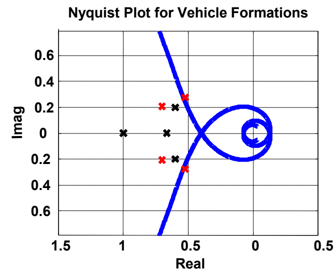
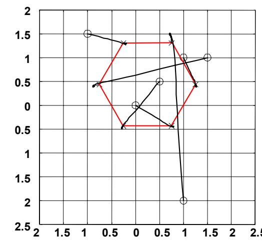
IFAC 2002



Communications Topology Captured through Di-Graph



Stability Analysis



Formation Stabilization

Approach

- Use graph theory, dynamical systems, and control to understand how communication topology affects stability
- Design control laws that make more sophisticated use of networked information for cooperative control

Accomplishments

- Developed conditions for insuring stability of interconnected with complex networked communications topologies
- Developed information flow design techniques for high performance reconfiguration of multi-vehicle systems

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We consider the problem of an interconnected set of control systems (vehicles) performing a coordinated task. We assume that the only connection between the vehicles is through the task that they are trying to accomplish (as opposed to dynamic coupling through the vehicle dynamics). In this setting, we consider the simplest problem where the inputs to a vehicle are a (possibly weighted) sum of the outputs from other vehicles. This would be the type of topology that would occur if the vehicles were trying to maintain an average position or track a common target.

In this setting, we derive conditions for the stability of the resulting system that explore the role of the *topology* of the information flow. We do this by modeling the information flow through the Laplacian associated with the directed graph that models the interconnection between the inputs and outputs of the vehicles. We show that in the case of identical, linear dynamics for the vehicles, the stability of the system can be determined by applying the Nyquist criterion, using the eigenvalues of the Laplacian in place of the loop gain. This result is particularly insightful in this context because there is a large amount of work in graph theory relating the eigenvalues of the Laplacian to the connectivity of the underlying graph.

We have also designed a technique for evaluating the role of information flow in achieving consensus (for example, on the location of the center of the formation) and improving performance by designing an auxiliary information flow loop that complements the sensed information between the variables. Using these techniques, we are able to get fast convergence to a desired formatoin.

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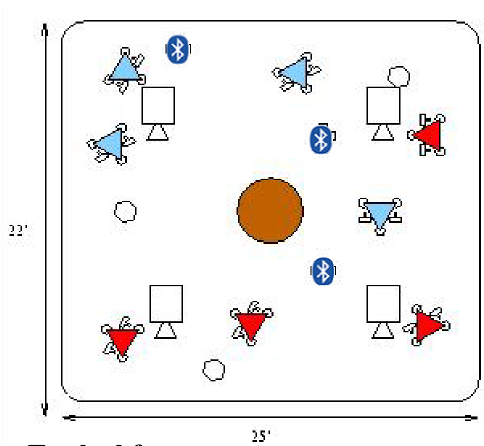
CDC 2002

Multi-Vehicle Wireless Testbed for Integrated Control, Communications, and Computation (DURIP)



Testbed features

- Distributed computation on vehicles + command and control console
- Point to point networking (bluetooth) + local area networking (802.11)
- Overhead vision system provides global position data (LPS)

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In addition to theoretical work on information flow, we are implementing our results on a new testbed that has built at Caltech (under DURIP funding). The testbed consists of

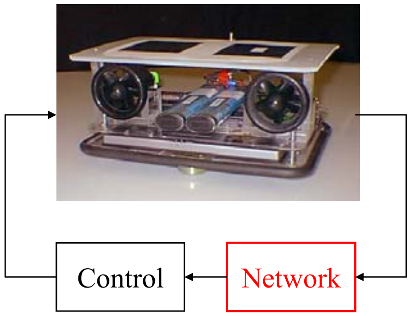
- •8 mobile vehicles with integrated computing and communications, including wireless Ethernet (802.11), Bluetooth, and infrared communications capability
- •1 fixed communications node, capable of broadcasting on multiple channels, connected to fixed computing platforms
- •A set of overhead cameras that can be used to provide position information to the vehicles (simulating GPS information across the wireless Ethernet network)
- •A command console consisting of computing and communications nodes

A unique feature of the testbed is the use of vehicles that have second order dynamics, requiring real-time feedback algorithms to stabilize the system while performing cooperative tasks. Work to date has succeeded in developing controllers for stabilizing multiple vehicles relative to each other, using different information flow topologies.

More information on this testbed is available on the web:

http://www.cds.caltech.edu/~murray/projects/durip01-mvwt

Real-Time Control Across Communication Networks



Research Questions

- Channel effects: how do changing channel conditions (fading, erasure, etc) affect closed loop control?
- Network effects: how do we code information into packets and route packets across network to achieve maximum performance in presence of variable latency and dropped packets?

Approach

- Model system as jump Markov process, with Markov-controlled, linear systems for each channel condition
- Explore use of multi-description codes for feedback control in presence of network latency and packet loss

Accomplishments

- Extended existing conditions for control of jump Markov processes to include estimator for channel condition in closed loop control algorithm

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In our most recent work, we have begun to consider in more detail the effects of the communication channel and communication network on the behavior of a closed loop control law. Our goal is to develop a framework for packet-based control theory that allows control using packetized data rather than continuous signals.

Our preliminary results look at the effects of the communication channel on the stability of the closed loop system. We model the channel as a set of linear systems, with the specific system being chosen according to a Markov process. This class of systems, known as jump Markov processes, have been studied in the literature and conditions are known for stabilization in the case that the Markov state (which captures the communication channel currently being used) is known to the controller. We have extended these results to allow an estimate of the Markov state and we give conditions under which the overall system is stable. These results are being written up for submission to the 2003 American Control Conference.