Elective in Robotics 2014/2015

Analysis and Control of Multi-Robot Systems

Introduction to the Course

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Organization

Lecturer:

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Course Web-site:
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Schedule:
28/4/2015: 15:45-17:15; 17:30-19:00  (room A4)

29/4/2015: 15:45-17:15; 17:30-19:00  (room A4)

5/5/2015: 15:45-17:15; 17:30-19:00  (room A4)

6/5/2015: 15:45-17:15; 17:30-19:00  (room A4)
Organization

• Goals of the course:
  • Provide some theoretical tools for analyzing and synthetizing cooperative behaviors in multi-robot systems
  • Use these tools to illustrate some recent applications
    • In simulation
    • With real experiments (quadrotor UAVs)

• Topics of the course:
  • Algebraic Graph theory
  • Decentralized Control and Estimation
  • Consensus-like protocols
  • Graph Connectivity and Graph Rigidity
  • Passivity Theory
  • Port-Hamiltonian modeling
  • Formation Control
Multi-Robot Systems

Multi-Robot Systems are systems composed of multiple interacting dynamic units.

biologically inspired…

shimmering of giant honeybees

synchronizing fireflies
Science 22 159(3821):1319-1327.
Multi-Robot Systems

Multi-Robot Systems are systems composed of multiple interacting dynamic units.

Synchronization
An agreement by multiple systems on a common state

Coordination
Managing of multiple interacting systems to achieve a team objective
Multi-Robot Systems

Multi-Robot Systems are systems composed of multiple interacting dynamic units.

Semi-Autonomous Haptic Teleoperation Control Architecture of Multiple Unmanned Aerial Vehicles

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"Experiments with 4 quadrotor UAVs"
Course Goals

• **Modeling** of multi-robot systems
  • Dynamics
  • Interconnections

• **Analysis** of multi-robot systems
  • Stability and performance
  • Convergence

• **Applications** of multi-robot systems
  • Formation Control
  • Localization
  • Bilateral Shared Control
Course Goals

• Graph Theory
  • Algebraic graph theory

• Consensus and Agreement Protocols
  • undirected/directed communication

• Networks as Systems
  • graph theory ⇔ systems theory
Course Goals

• Exploit energy-based techniques:
  • passivity
  • port-Hamiltonian modeling

• Passivity:
  • general and powerful framework
  • linear/nonlinear setting
  • related to I/O stability

• Port-Hamiltonian modeling
  • approach to model interconnected systems
  • based on the “energy flows”
  • strong link with passivity

• Applications
  • formation control of UAVs
  • connectivity maintenance
  • navigation and exploration

Robuffo Giordano P., Multi-Robot Systems: Introduction to the Course
Networked Dynamic Systems

• **Decentralization**: limited sensing/communication and/or computing power

• Every agent must elaborate the gathered information to run its local controller

• The controller complexity is related to the amount of needed information

• If the whole state is needed, the complexity (~ computing power) increases with the number of agents
  • May easily become infeasible
  • And would need to know the whole state…
Course Goals

• Another example of coordination

• The wheels must “coordinate” their orientations and spinning motion

• The result is a coordinate displacement of the “shared” platform chassis

• However, this is not exactly what we’re aiming at!

• **Centralization**: this system is completely centralized
  • The wheels have no “independent brain”
  • A single central unit knows the whole state and commands the wheel actions
  • No constraints on sensing and communication
  • What if instead of 4 wheels, there were 100 wheels? The controller (and communication) complexity grows with the number of components
Course Goals

• In this example, no central unit is present

• Every agent has “its own brain”

• Relative communication and sensing depends on the current state
  • within some range
  • in visibility (no occlusions)

• The complexity of each agent controller doesn’t depend on the number of agents

• Of course:
  • harder to design
  • harder to analyze
  • but closer to how nature works!
**Passivity**

- Passivity: intuitively, something that does not produce internal energy.
- A generic nonlinear system
  \[
  \begin{align*}
  \dot{x} &= f(x) + g(x)u \\
  y &= h(x)
  \end{align*}
  \]
  is said to be passive if there exists a storage function
  \[V(x) \in C^{1}: \mathbb{R}^{n} \rightarrow \mathbb{R}^{+}\]
  such that \(\dot{V} \leq y^{T}u\) or equivalently
  \[V(x(t)) \leq V(x(t_0)) + \int_{t_0}^{t} y^{T}(s)u(s)ds\]
  Current energy is at most equal to the initial energy + supplied energy from outside.
- This condition can be interpreted as “no internal generation of energy”
• An intuition: proper interconnections of passive systems are passive

\[ E_{\text{out}} \leq E_{\text{in}} \]

• Is this a general fact?
• Can we reduce a passive system into the “proper interconnection” of atomic passive sub-systems?

• Is there a network structure behind passivity?
  • ... network structure -> multi-robot
  • ... network structure + passivity -> port-Hamiltonian Modeling