Multi-Robot Path Planning
From Theory to Practice and Back Again

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What are control systems?

Information-based decision making in dynamic and uncertain environments.

What are control systems?

Information-based decision making in dynamic and uncertain environments.

- *Automotive:* Cruise control, engine speed control, emission control, antilock braking, traction control, active suspension, **self driving cars**, etc
- Robotics, aeronautics, communications, electronics, transportation, manufacturing, biomedical, etc

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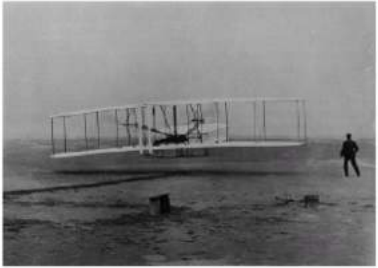
The enabling technology



Men already know how to construct wings or airplanes...Men also know how to build engines...[that] drive these planes at sustaining speed...Inability to balance and steer still confronts students of the flying problem...When this one feature has been worked out, the age of flying will have arrived, for all other difficulties are of minor importance.
Wilbur Wright, 1901

The "hidden" technology

- Enabling...but unmentioned
- Easier to talk about "devices" rather than "concepts"

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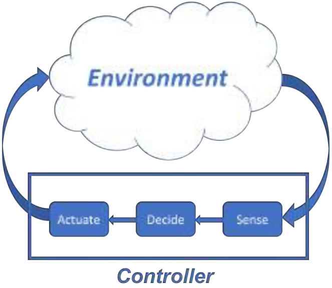
Figure 1. *Gripen JAS39 prototype accident on 2 February 1989. The pilot received only minor injuries.*

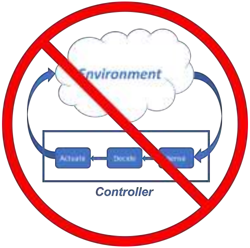
- *Not usually discussed... until something goes wrong*
- "Ferry owner fined after control system failure" (May 2017)
- "EU's air traffic control system failed, and up to 15,000 flights may be grounded" (April 2018)

Traditional architecture



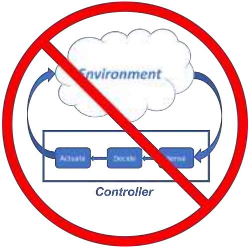
- Central information
- Central authority

Distributed architecture



- Overlapping information
- Distributed authority

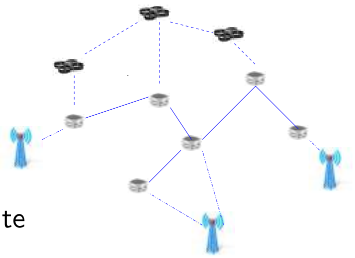
Distributed architecture



- Overlapping information
- Distributed authority
- *Decision quality of individual affected by decisions of others*

Realtime Distributed Motion Planning: Setup

- *Collection of mobile robots*
  - Limited computation
  - Limited communication
  - Limited power
  - Sensitive to time-delay



- *Communication network*

$$(A)_{ij} = \begin{cases} c_{ij} & \text{i \& j can communicate} \\ 0 & \text{Otherwise} \end{cases}$$

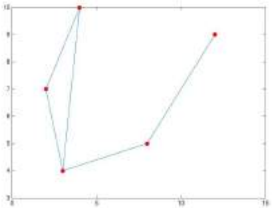
Rendezvous Problem

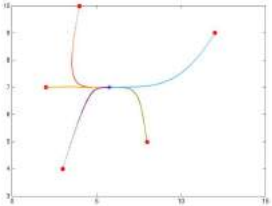
Consensus Equation

$$\dot{x}_i = -\sum_{(i,j)\in E} (x_i - x_j)$$

$$\dot{x} = -\mathcal{L}x$$

$x \in \mathbb{R}^N$ and $x_i \in \mathbb{R}^2$ for all $i \in \{1, 2, \ldots, n\}$

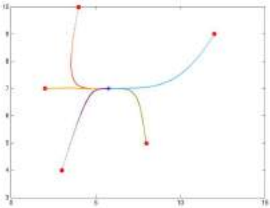


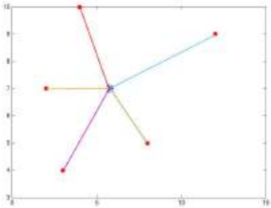


Optimization Problem

Consensus Equation is the solution to the following optimization problem

$$\min_{x} \frac{1}{2} x' \mathcal{L} x$$





No cost assigned to energy

Rendezvous Problem

MPC Based Algorithms

$$J(x,u) = \sum_{k=0}^{T_p-1} \left(x_k' \mathcal{L} x_k + u_k' R u_k \right) + x_T' \mathcal{L} x_T$$

$$x_{k+1} = x_k + u_k,$$

T_p is the prediction horizon.

- Energy cost is included
- Guaranteed convergence to consensus set

MBZIRC 2017 (March 16 - 18)

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Prize: USD 1,000,000


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Mohamed Bin Zayed International Robotics Challenge
inspiring the future of Robotics صياغة مستقبل الروبوتات

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MBZIRC 2017: Lessons Learned

- Early working prototype
- Iterative design process
- Design decisions
  - off the shelf vs in-house
  - Sensor selection: operating limitations and operating environment
  - Algorithm selection/design

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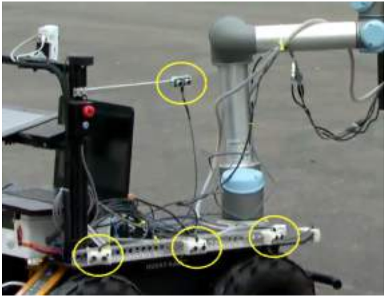

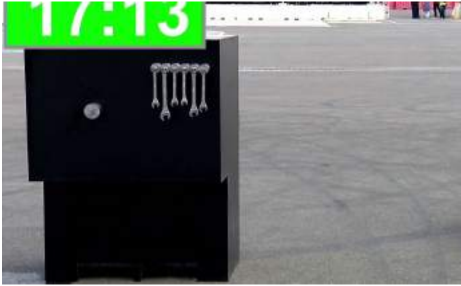

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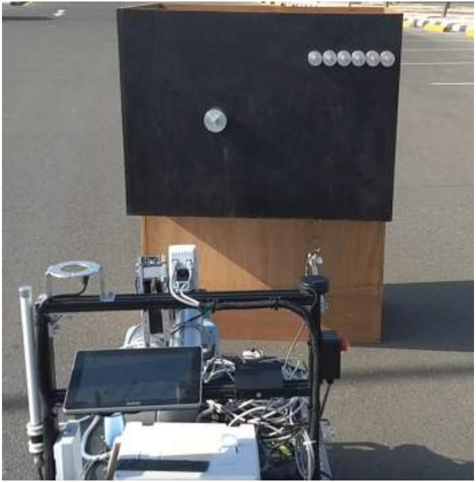

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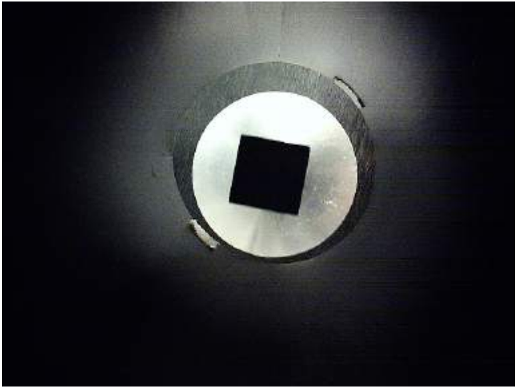

Respect The Unstable

Gunter Stein

(Bode Lecture)

[“Two trends that threaten to undermine the achievements of controls research community ”]

Respect The Unstable

Gunter Stein

(Bode Lecture)

[... "the increasing worship of abstract mathematical results in control at the expense of more specific examinations of their practical, physical consequences. "]

Rendezvous Problem

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Limitations

- Significant communication overhead
- Slow convergence

Motivation

Objective

A distributed framework to strike a balance between

- global performance, and
- the cost of distributedly computing a control action.

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A distributed framework to strike a balance between

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Local interaction laws

- Real time implementable
- Limited communication overhead
- Performance guarantees

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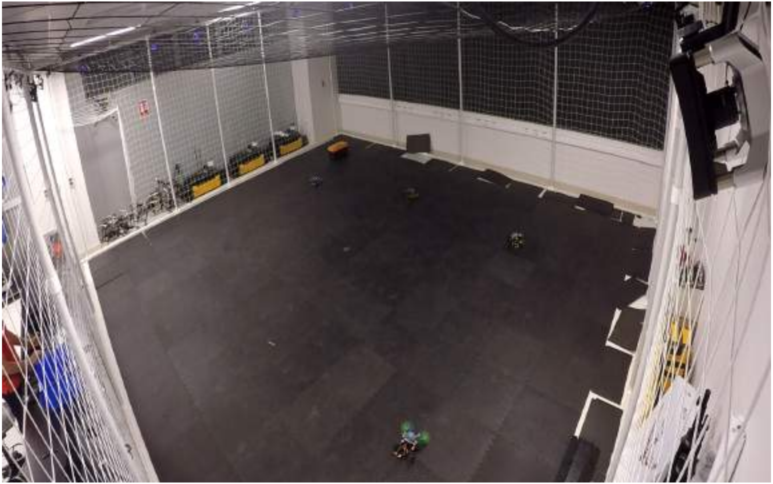

Thank You