Comments on Autonomous Systems and Processes

AFOSR Workshop:
Adversarial and Stochastic Elements in Autonomous Systems

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Science of Autonomy

DoD Announces $400 Million Investment To Basic Research (7 Nov 2008), cf., http://www.defenselink.mil

> "Topics for the initial funding will focus on the following areas of technical challenge: counter weapons of mass destruction (WMD), network sciences, energy and power management, quantum information sciences, human sciences, science of autonomy, information assurance, biosensors and bio-inspired systems, information fusion and decision science, and energy and power management."

- Science of Autonomy

  CYBERNETICS: or control and communication in the animal and the machine

  -Norbert Wiener (1948 and MIT Press, 2nd Edition 1961)

Autonomous Systems and Processes

- Control of nonequilibrium phenomena
  » Agile autonomous flight
    – Tradeoffs: agility & cpu
- Network centric, enterprise-wide, distributed dynamic operations
  » Robust adaptive networked systems (RANS)
  » Control of/over networks
- Integrated sensing, processing and actuation
  » Integration of autonomic system (sensorimotor system) with processing and decisionmaking
    – data ➔ information ➔ knowledge ➔ action
  » Adaptive exploratory data/information acquisition & analysis and decisionmaking
  » Massive amounts of real-time streaming data from heterogeneous sources

Autonomic Systems
Self-* Systems

- A^3 – automatic, adaptive, aware
  - » * = configuration, healing, optimization, protection, …
- Autonomic Computing & Networking
  http://www-01.ibm.com/software/tivoli/autonomic/
  http://nsfcac.arizona.edu/
  http://dssg.cs.umb.edu/wiki/index.php/BiSNET/e
- Autonomic network architecture (ANA)
  http://www.ana-project.org/
- Autonomic Logistics
  lockheedmartin.com/products/
  AutonomicLogisticsInformationSystem

MADMs: Agile Autonomous Systems

AGILITY

Ability to maneuver with minimum turn radius in minimum time in response to commands and <u>sensed</u> environmental stimuli.

MOTIVATION

- **Hidden, Occluded Targets**
- **Target Uncertainty, Mobility**
- **Stealth, Covert Operation**

➔ Operation in Confined Airspace
  - **Collision Avoidance**
  - **Datalink Dropout**
  - **Situational Awareness**

TECHNOLOGIES

Aerodynamic Agility
  - **Agile Airframes, Propulsion**
  - **Active Aerodynamic Flow Control**

Guidance Agility
  - **Autonomous Imaging Guidance**
  - **Wide Field-of-Regard Sensing**

Precise Lethality

Agile Autonomous Flight

- Is there a way to achieve all of the "desirements" for agile autonomous flight?
- It seems an almost impossible task
- For inspiration we ask, "What animal, by far has been the most deadly to the human race?"

The Mosquito

- Flight speeds
  - Translation 1-1.5 mph
  - Able to hover
- Can recognize prey from 35 feet away
- Fueled by tiny amounts of blood
- Has been known to carry lethal payloads
- Has an advanced control system
- Utilizes advanced flow control through wing manipulation and some morphing
- Does it all with almost no brain

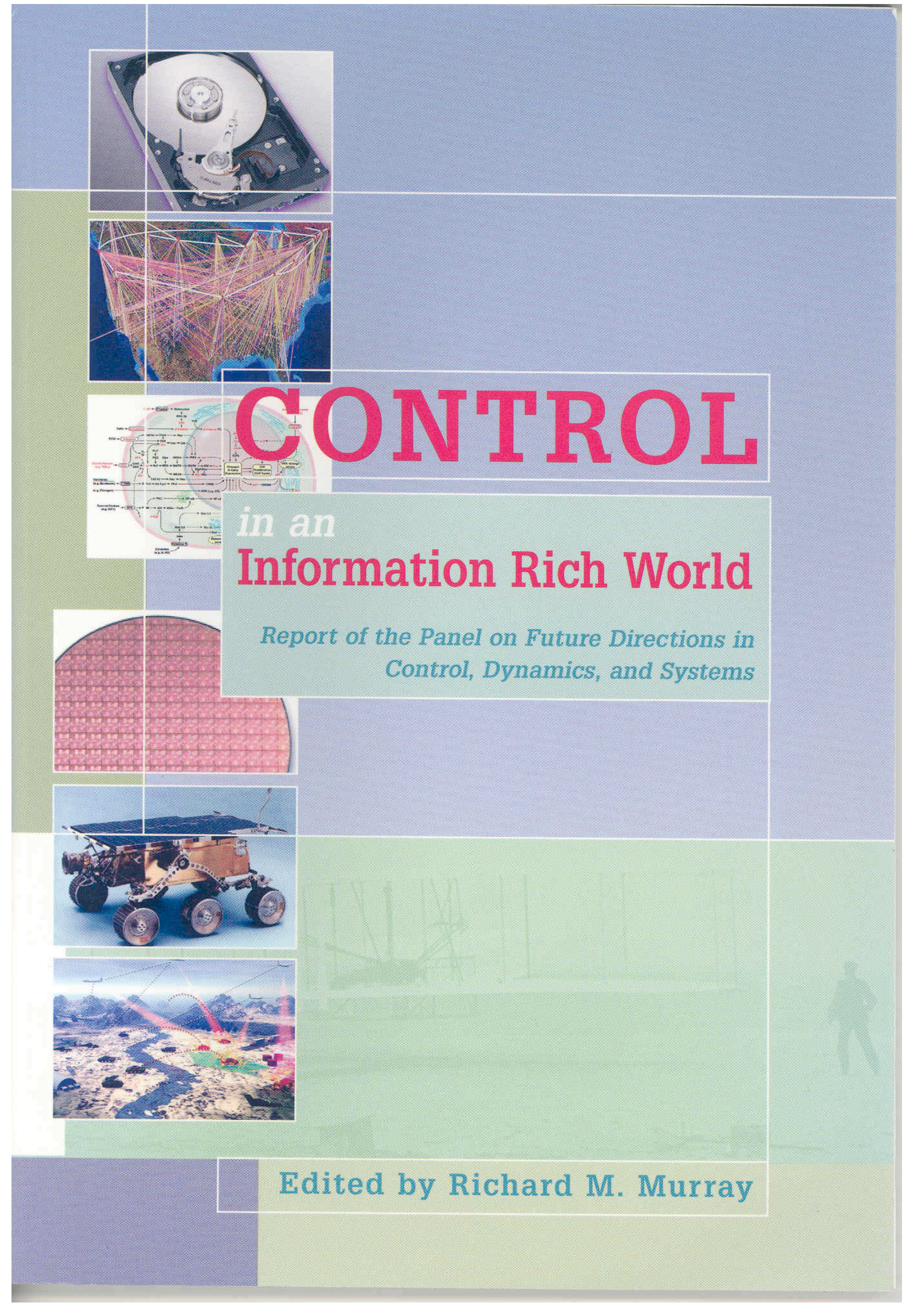
"Reverse engineering" of biological systems?

"… One of the biggest challenges facing the field is the integration of computation, communications, and control. As computing, communications, and sensing become more ubiquitous, the use of control will become increasingly ubiquitous as well…."

- Unified theory integrating computation, communications, control, and thermodynamics

http://www.cds.caltech.edu/~murray/wiki/Top_Ten_%28Challenge%29_Problems_in_Control

Published by SIAM & IEEE
Control Systems Magazine 2003



Cooperative Control Dynamic & MultiScale in Time and Space

CoopCon: Examples

- R&D Portfolio Selection
- "Swarms": integrated ISR & attack in uncertain adversarial environments
  - » Urban canyons, caves, …

<u>Desirement or Hope?</u>

- Robust Decision Theory?
  - » Reliable, scalable, …

Game Theory, Dynamic Programming, …

- Dynamic, distributed, adversarial agents
  - » Everything is time dependent and uncertain
  - » Cost of time and resources to gather & analyze new information
  - » Asymmetric capabilities
- Scalability, computational complexity
  - » Transient behavior critical
  - » Heuristic methods, but with some mathematical substance

"Games are among the most interesting creations of the human mind, and the analysis of their structure is full of adventure and surprises. Unfortunately there is never a lack of mathematicians for the job of transforming delectable ingredients into a dish that tastes like a damp blanket."

-In J. R. Newman (ed.) The World of Mathematics, New York: Simon and Schuster, 1956.

BACKUP CHARTS

Richard Murray/Caltech

http://www.cds.caltech.edu/~murray/wiki/Top_Ten_%28Challenge%29_Problems_in_Control

1. **World Cup Robotic Soccer Team. Design a robotic soccer team that is good enough that it can compete against humans in the World Cup (and win!). The robots should have the mass and volume of a human being. If we could do this, we could probably design robotic search and rescue teams, security forces (police, firefighters, combat teams), and other collections of robots that perform cooperative tasks in unstructured environments. Target date: 2025.**
2. **InternetRT. Redesign the Internet so that it could be used to provide real-time (RT) connections between sensors, actuators, and computation that had arbitrary geographic locations. This could revolutionize the way we do control, perhaps even allowing control laws to reside in the computers of consulting companies who would sell them as services (this cool idea is courtesy of Craig Smith at Texas A&M). It might also be useful for global service and supply chains and defense systems (eg, missile defense). Target date: 2005 for the protocols, 2010 for the implementation.**
3. **Dynamically Reconfigurable Air Traffic Control. Design the air traffic control system so that passengers always got to their destination on time, with a plane that was always 90+% full, and with no delays due to weather anyplace in the country except your departure or arrival city. Supply chains and the power grid could probably benefit from the resulting technology as well. Target date: 2008.**
4. **Human Life Stabilization Bay. Design a medical system that, when connected to a human through biometric sensors and drug delivery systems, can diagnose a human being and keep it alive indefinitely. Target date: 2015.**
5. **Redesign the Feedback Control System of a Bacteria. Scientists are able to genetically modify microbiological organisms so that they produce certain chemicals or change their behavior. Can we redesign the control systems in bacteria (including implementation!) so that we can program their behaviors in response to external stimuli? Possible applications include new types of medical treatments and in vivo sensing systems. Target date: 2008.**
6. **Control 101. Develop a single, unified curriculum for teaching undergraduate control that is a required course for all engineering disciplines (including computer science!) and is sought out by students from the sciences and mathematics as a essential part of their education. Make the principle of robustness through feedback as common as the knowledge of Moore's law. Target date: 2005.**
7. **Packet-Based Control Theory. Develop a theory for control in which the basic input/output singles are data packets that may arrive at variable times, not necessarily in order, and sometimes not at all. Related problems including figuring out how to do the source coding to support such networked control systems ("real-time information theory", in the words of Sanjoy Mitter). Target date: 2005.**
8. **Slow Computing. Build a computer capable of powering a PDA out of devices with 10 msec (100 Hz) switching times. Our brain is able to function at the level of a PDA (perhaps higher) but the "devices" in our brain have time constants measured in milliseconds. Can we design and build similar systems? Target date: 2010. [added 25 Oct 05]**
9. **Write a 100,000+ line program that works correctly on first execution. Engineers in other areas are able to design relatively complex systems that are built for the first time in full working condition (Boeing 777, FETT). Can we do this for software systems? Part of the difficulty is the interaction with "unknown" components (operating systems, libraries, etc). [added 25 Oct 05]**