

Nanosystems Control Engineering for Medical Applications

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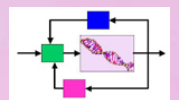
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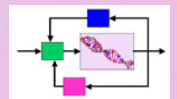
Workshop Title

Biomedical Robotics and
Biomechatronics: **Scientific and
Technical Foundations of a new
Interdisciplinary Field for
Research, Medical Application and
Industry**



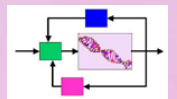
Nanosystems Control Engineering for Medical Applications

What are the fundamental questions, design requirements and open problems involving the control of “nanorobotic” systems for medical applications?



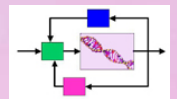
Nanosystems Control Engineering for Medical Applications

- Nanomedicine is a new area of application for control theory
- There is a need to develop relevant theory and useful mathematical tools
 - For improved understanding and design
 - To facilitate diagnosis and intervention
- Control methods for these systems must take into account safety and efficacy requirements



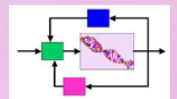
Attributes common to many biological and biomedical control systems

- Inherent nonlinearities
- Embedded discrete event structures
- Time-varying and stochastic aspects
- Either simplistic models or detailed models with many unknown (and hard to identify) parameters



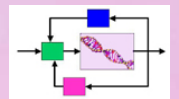
Special aspects of anticipated nanomedical systems

- Unusual properties of communication channels (such as substantial, time-varying random communication delays)
- Self-organizing behavior of components



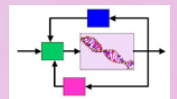
“Nanoswarm” Control

- Consider an idea present in many works of science fiction-
-aspects of which are now approaching feasibility
- What are the control problems?



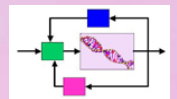
“Nanoswarm” Idea

- Swarm of nanoparticles, traveling through the blood stream or injected in the vicinity of a solid tumor
- They possess receptors to tumor antigens, allowing them to “home in” on the tumor
- They also have a magnetic component permitting them to be steered, imaged or recovered



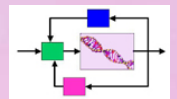
“Nanoswarm” Idea

- At targets, the particles self-assemble
- The resulting nanoparticle assembly might release treatment drugs
- It could be used to target external treatment (eg, focused ultrasound, laser light for heating or phototherapy)
- It might include imaging contrast agents, making it easier to identify the location and spread of the tumor



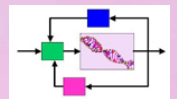
“Nanoswarm” Control Problems

- Guiding the particles to the desired locations, with the desired distribution, is a control problem
- If nanoparticles can recognize targets using multiple characteristics, there will be a need for local computation
- If externally directed, there are communication and control problems



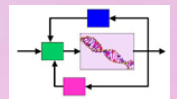
“Nanoswarm” Control Problems: Self-Assembly Issues

- Nanoparticles will need to communicate and coordinate with each other, in some sense, to adequately cover/surround the target for diagnostic or treatment purposes



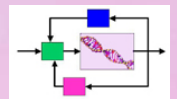
“Nanoswarm” Control Problems: Treatment Control

- Possibly pre-programmed treatment, done autonomously by nanoparticles
- Possibly externally-triggered action of nanoparticles (one-way or two-way communication required)
- Possibly “telerobotic” control of the swarm, by external operator/surgeon
 - Communication time delays (random and variable) are an issue of major importance



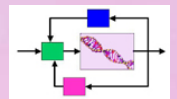
Control Theory for Nanoswarms

- Environments where the communication time delays are of the same order of magnitude as the system dynamics has not been well-studied by control theorists
- In most engineering systems, communication is very very fast, compared to device dynamic response times



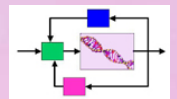
Control Theory for Nanoswarms

- Coordination and control of very large numbers of semi-autonomous agents and self-assembling devices
- Existing methods are not feasible due to the computational load--given the very large number of individual components
- Local autonomous computation must exist in a very small package



“Nanoswarm” Control Problems: Termination Issues

- Breakdown into safe and non-toxic waste that organism can dispose of
- Possible collection of particles and removal
- Fail safe operation--how do you turn the system off, and prevent undesired actions?
- A special concern if nanoparticles are biological (such as viruses, plasmids, etc) which might be contagious



New Control Theory and Methods Are Needed

- My bias: Best results will come from collaborative work between experimentalists, theoreticians and medical practitioners

