Bio-inspired Autonomous Engineered Systems

(All PDs of ENG, MPS, BIO and CISE)

Development Background

1. Extramural (community) Blue Ribbon Panel study ‘06-’07

2. Internal (NSF) development of interdisciplinary research frontier at the interface of 4 Directorates ENG, MPS, BIO and CISE in “Biosensing and Bioactuation”) ‘07

---NSF Internal Symposium: 07/31/07 (Report to ADs: 10/05/07)

3. Integration of internal & external developments
---Extramural BioS & BioA Workshop, 11/27 & 28/07 (Report to ADs 01/07/08)

This EFRI represents the consolidated context of the quadrilateral frontier research on BioS & BioA
Purpose: Develop new integrated knowledge for creation of engineering systems and devices with embedded human-centric and bio-inspired intelligence and autonomy

Application: Better life quality, health, safety and security
Biological Intelligence

Machine vs. Biology

Bald eagle
44 mph
10 lb

Boeing 747
583 mph
850,000 lb (max takeoff weight)

Cheetah
114 km/h (72 mph)

Bullet train
Over 300 km/h
Biological Systems and Man-made Systems
(Real Time Decision Making/Actuation)

Formation flight

Vehicle platoon (Automated Highway Systems by Calif PATH)

Bio-inspired Robots:
Dragonfly Robot and Boxfish Robot
Research Thrust Areas

1. Hierarchical Organization of Biological Systems
   --determine the subtleties underlying the growth of hierarchical bio-systems, and their use in sensing and actuation; apply to new multi-scale and multi-functional engineered systems

2. Sensor Informatics Guided by Life
   --Understand and emulate data mining and prioritization, as well as decision-making processes, in living organisms to facilitate monitoring, assessment, and control of complex engineered systems in sensor rich environments
Research Thrust Areas

3. Multi-functional Materials and Devices for Distributed Actuation and Sensing

-- Through understanding of biological systems, their ability to exhibit fault-tolerant actuation under control with a wide dynamic range, develop new composite material systems that can retain some of nature’s behavioral characteristics

4. Forward Engineering & Design of Biological Components & Systems

-- Synthesize hybrid mechanical/electronic/living systems through system-level integration of biological and engineering components that sense, actuate, compute, regenerate, and efficiently reallocate resources to achieve desired responses and functions
Integration of Engineering and Biosciences- Examples

- Using microfluidic incubator arrays to study environmental pressure on bacterial, viral, etc. evolution/selection
- Understanding interaction between fluid dynamics, cell orientation, raft formation, and cholesterol absorption issues resulting in plaque formation in the arterial passages.
- Solid-fluid interaction computational modeling of lung behavior, so that effects of scar tissue, resections, and other abnormalities can be observed on compliance, particle deposition etc.
- Novel design of bioreactors (magnetic) to grow larger tissues for different studies i.e., long arterial

Transformative Ideas & Research

- New generation bio-inspired sensors and actuators mimicking human senses & control
- Autonomous systems with cognitive capabilities mimicking self awareness and learning
- New paradigms of sensor fusion and on-line informatics
- Human-like cognitive robotic systems
- Multi-functional materials & morphic systems: design & control
Management Plan and Budget

- Management Team: one member from each participating ENG division plus one each from MPS, BIO and CISE, with balanced device and systems expertise
- Estimated budget requirement: $10-15M total
- Multi-disciplinary team (minimum 3 PIs/coPIs) proposals only, with PI from an Engineering Department
- Standard grants for 4 years duration at max $500K/yr
- Estimated number of proposals: 100 (PIs/co-PIs must be from different disciplines [3 minimum])
- Estimated number of awards: 5-7

Future Path of the Community

- Fundamental EFRI research on this topic will create:
  - New paradigms for Biosensing & Bioactuation R&D
  - New technologies and tools for health care, search and rescue, etc.
  - Technology-driven wealth and job creation, and enhanced national security
- A new interdisciplinary research community will be created to provide intellectual leadership in Bio-inspired Autonomous Engineered Systems
- Talented graduate students will go on to become:
  - Interdisciplinary academic leaders
  - Entrepreneurs leading start-up companies
  - Bridges to the global community
Samples of Proposal Titles

Sensors & Informatics

- Nano-engineered artificial neuron circuitry for multimodal signal processing and control
- Soft polymer micro-systems with integrated sensing, control and energy harvesting capability

Bio-inspired Active Materials & Devices:

- Active material-based actuators for flying “insect” robots
- Flipper-driven bio-autonomous vehicles for underwater monitoring and exploration
- Self-controlled knee implants with energy harvesting mechanism
- Toxic-free biomaterials for nano-robot surgery systems
Samples of Proposal Titles

Civil Infrastructures & Other Systems

- Smart skins for civil structures
- Self-regenerated, self-healing engineered systems
- Bio-mechatronic micro/nano robots for search & surveillance
- Bio-reactive materials and structures for impact mitigation

Backup Slides to follow
Self–Powered Hybrid Forisome Nerve System

Objective: produce a sensory nerve system for civil structures by using forisomes as the mechanoreceptors, nerve fibers, and spinocervical tract to the nodal and central processing units.

Reconstruction of a sieve element of the Vicia faba with a forisome (red) located close to a sieve plate (blue); other membrane structures in green. The forisome shown is 30 µm long. Forisome can swell/deswell in response to stimuli.

Online Informatics

Optimal use of information for effective real-time decision making and system control for infrastructure and the environment

Current Challenge: The continuous growth in our ability to collect and disseminate data and information results in the likelihood of data inundation

Research Thrusts

- Multiple strategies to acquire, store, transmit, aggregate, mine, validate, analyze, and visualize data
- Inference mechanisms for information trustworthiness and risk uncertainty.
- Cyber tools for diagnosis and prognosis for fast and robust extraction of essential features from the data and identify anomalies in highly uncertain and evolving environments.
- Ways of evaluating related social sciences, public policy, and human behavior
Bio-inspired SHM

**Biology Inspired**
- Dense network array mimics nervous system of living organisms
- Nodes will reassign their duties if one fails like ants in a colony

**Sociology Inspired**
- Information is transmitted through a hierarchy like soldiers in a chain of command
  - Sensor groupings act independently but communicate with a base station like countries in the UN