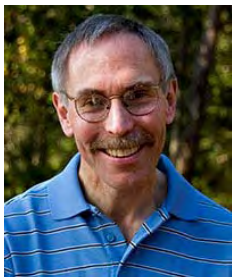
Mechatronics

Martin Berg 	Santosh Devasia 	Brian Fabien 
Joe Garbini 	Per Reinhall 	Eric Seibel 
Steve Shen 	Duane Storti 	Wei-Chih Wang 

What is Mechatronics?

Mechatronics is the integration of mechanical, electrical, and computer technologies into the design of complex products

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Illustrate with an example

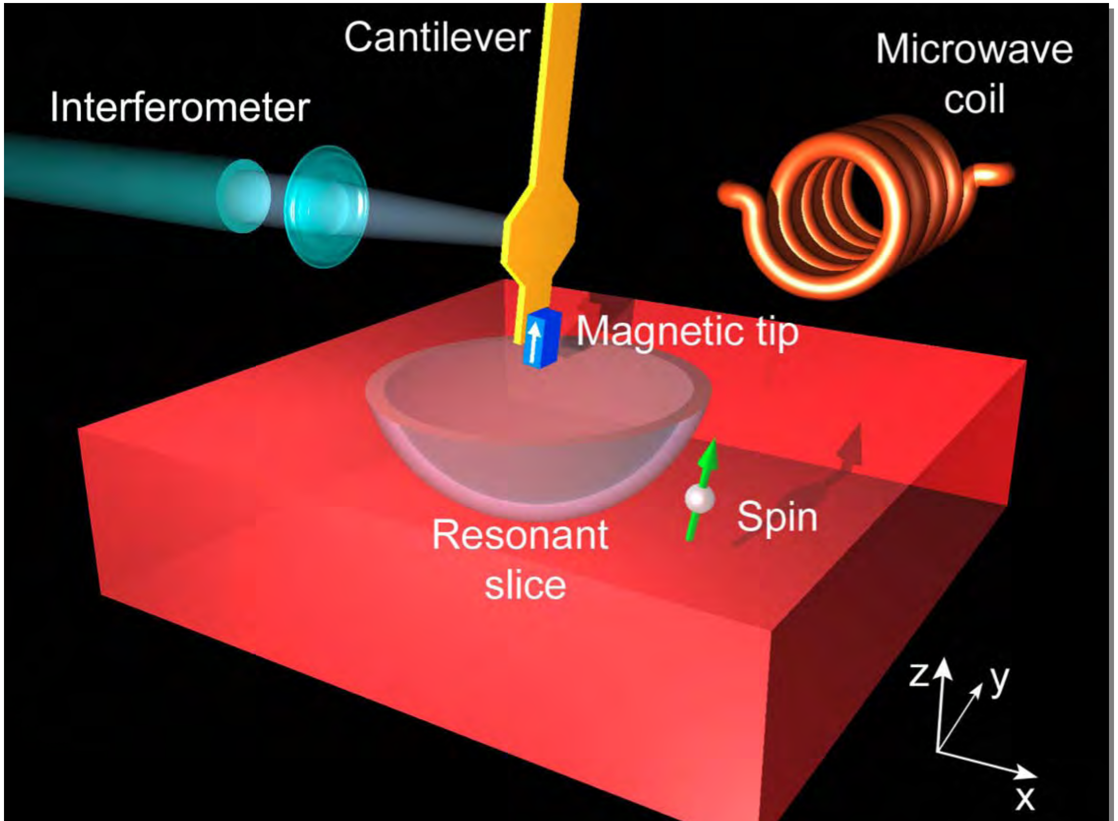
Magnetic Resonance Force Microscopy

By: Prof. Joe Garbini

Magnetic Resonance Force Microscopy

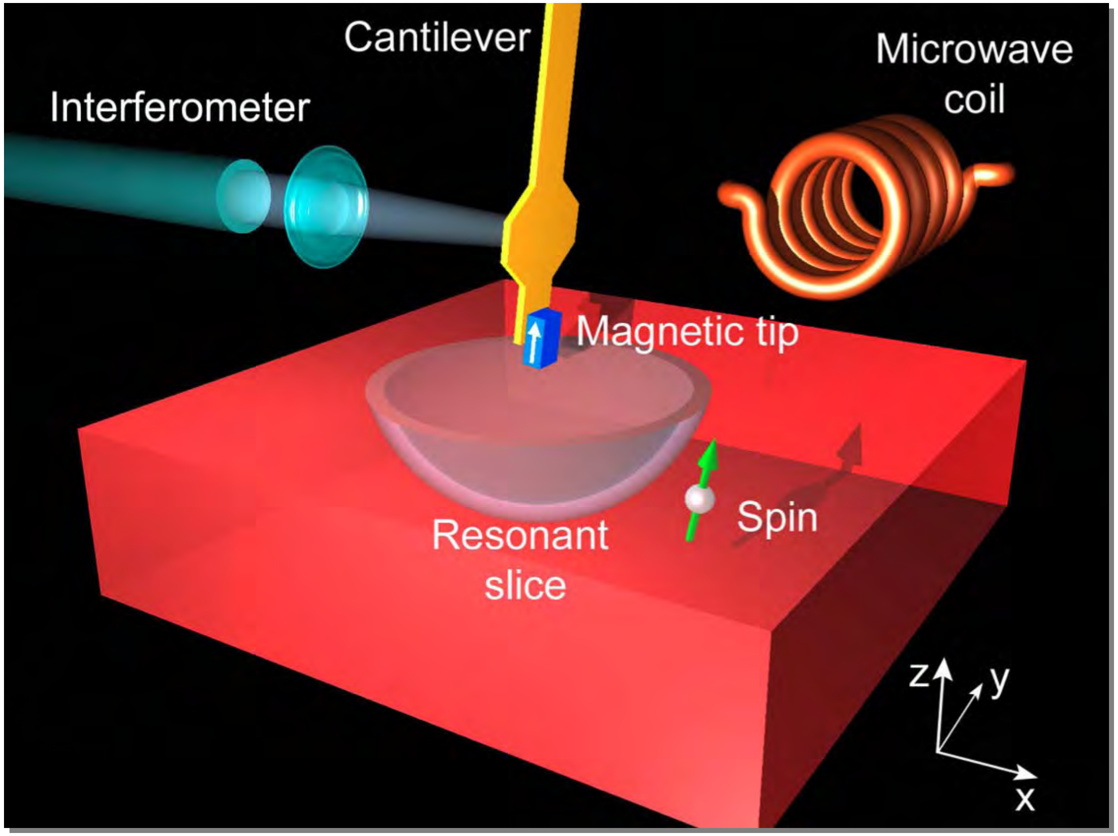
Goal: **Image the 3D atomic structure of individual molecules**

- **First conceived at UW**
- **15 years of effort**
- **ME involved from the start**
- **Now ~ 20 research groups internationally**



Challenge: - **Detection of exquisitely small forces (Zepto-newtons, Zepto = 10^{-21}).**

- Operates near the quantum limit.
- Subject to spin decoherence.
- Image reconstruction.



Challenge: - Detection of exquisitely small forces (Zepto-newtons!).
- Operates near the quantum limit.
- Subject to spin decoherence.
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MRFM funding: NSF, NIH, ARO, DARPA, IBM (Almaden).

Primary Current funding: - MURI (ARO), $1M per year, for 5 years (75% UW)

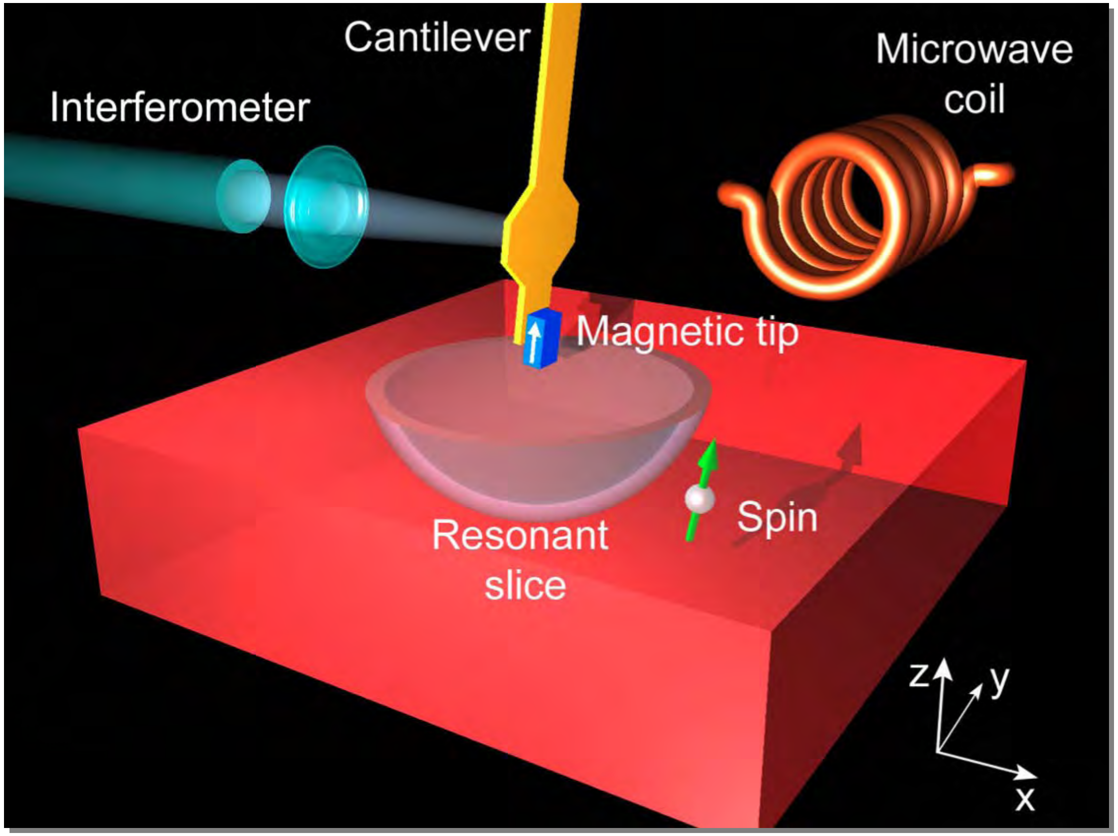
Goal: - Single nucleon detection.

Collaborators:
- Cornell: Prof. John Marohn
- U Michigan: Prof. Al Hero
- IBM: Dr. Dan Rugar
- **UW**
  - School of Medicine: Prof. John Sidles
  - Mathematics: Prof. Ann Greenbaum

Pedagogic Goal: Quantum Systems Engineering.

Research Issues

Mechanical Issues: Position and Thermal Control, Vibrations
Electrical Issues: Signal Conditioning
Computational issues: Data acquisition and controller implementation



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Mechanical Issues: Position and Thermal Control, Vibrations,
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Mechatronics is the integration of mechanical, electrical, and computer technologies into the design of complex products

Mechatronics builds on Core-ME-competency in Dynamics, Vibrations, Controls, Nonlinear Systems and Robotics

What drives Research in Mechatronics?

The need to improve performance

What drives Research in Mechatronics?

Need to improve performance

Two Examples

Example 1: by Prof. Steve Shen

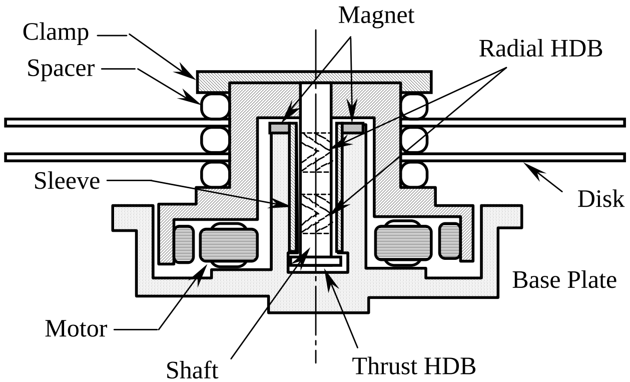
Improve Performance of Computer Hard Drives

Vibrations in Spindle Motors of Computer Hard Disk Drives

Professor I. Y. (Steve) Shen, ME Dept

Computer Hard Disk Drives

Fluid Bearing Spindles



Need to Improve Performance

(a) Increase Information density **(Small bits)**
(Approach: increase the number of tracks)

(b) Reduce data-access speed **(High Speed)**
(Approach: increase spin speed)

Problem: Small vibrations in the disc cause read/write error

Solution: New Technology : Spindle motors with fluid-dynamic bearings

Research Issues: Integration of two fields – fluids and nonlinear vibrations

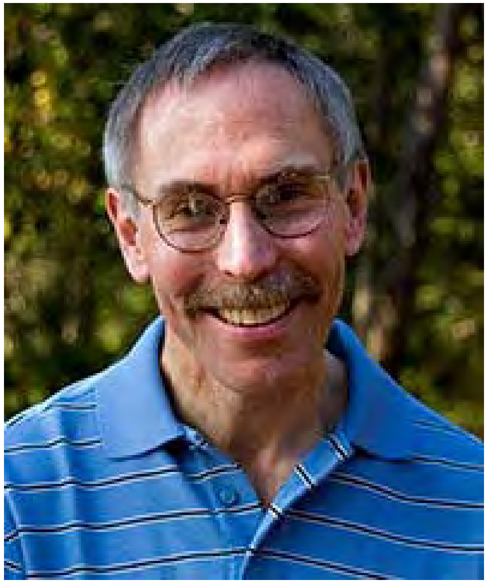
1. No mathematical models are available for design and optimization of disks/spindle.
2. Design is done by trial and error; long and expensive design cycles.
3. Almost no knowledge base is available.

Prof. Shen has a Strong History of Collaboration with Disk Drive Industry and Leadership Role in this Research Area

What drives Research in Mechatronics?

Need to improve performance

Second Example
by Prof. Martin Berg
Improve Performance of Large Robots



Adaptive End-Effector Position Control

- **Performance Improvement Objective:**
  Order-of-magnitude improvement in the accuracy to which the position of the end-effector of an industrial robot/machine tool can be controlled.
- **Research Issue:**
  Interface of different scales
  Large scale --- large range of robot
  Small scale --- need for precision positioning
- **Started with Local Collaboration**
  Boeing: Robot is shown in photo
- **Funding:**
  NSF funding to UW : $93K/year
  Period: September 2004-August 2007

Recap: What drives Research in Mechatronics

- Need to improve performance
- Interface of different scales – large range (large scale) robot with fine precision (small scale)
- Interface of different fields – fluids and vibrations in the fluid-dynamic bearings

What are New Opportunities in Mechatronics?

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New Scales:

(a) Nano

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New Scales:

(a) Nano

New Fields (Emerging applications)

(b) Bio

What do we want to do?

New Scales:

(a) Nano

New Fields (Emerging applications)

(b) Bio

What we want to do?

We want to Leverage Core-Competency when developing New Opportunities

Current expertise in
sub-nano scale positioning, control,
Modeling and fabrication.
Robotics, Instrumentation

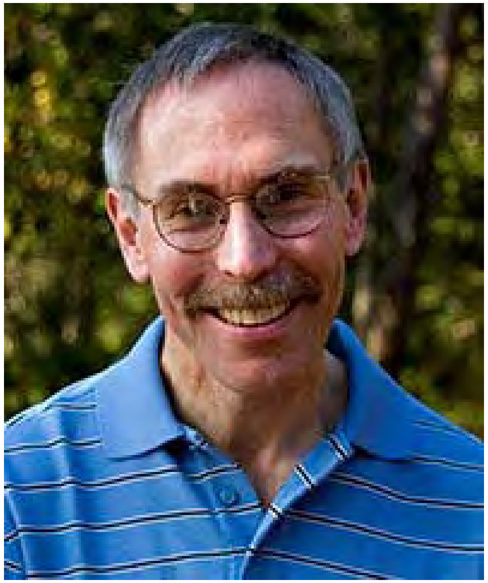
New Scales:
(a) Nano
New Fields (Emerging applications)
(b) Bio

Faculty are already exploiting new opportunities in Bio/Nano

Ping Ao	Modeling biological networks	Bio-medical
Martin Berg	Automation for Crystallography	Bio-medical Distributed Systems
Santosh Devasia	a) AFM Imaging of human cells b) Nanowire-Cilia-based Pumps	Nano/Bio-imaging Bio-fluidics
Joe Garbini	Imaging of molecular structure	sub-nano Bio-molecules
Per Reinhall	Biomedical sensors, Heat Valves	Bio-medical
Eric Seibel	Single-fiber endoscope	Bio-medical
Wei-Chih Wang	Instrumented Prosthetic Footwear	Bio-medical
Brian Fabien	Model Identification for Prosthetics	Bio-medical
Duane Storti	Nonlinear oscillations in Bio-systems	Bio-mimetic Design

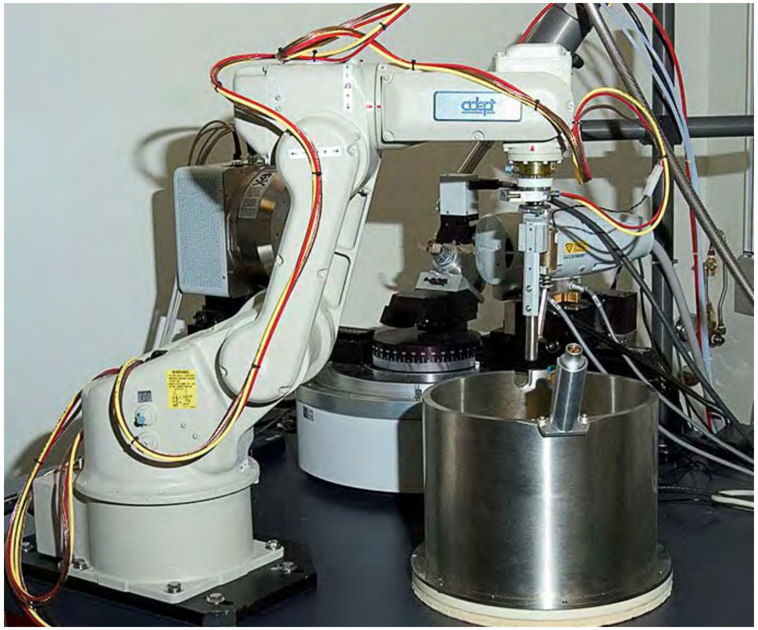
Detailed Example 1/3

Automated Screening
of Protein Crystals
By Martin Berg



Automated Annealing, Healing and Screening of Protein Crystals

- **Joint work** with Prof. Ethan Merritt, Dept. of Biochemistry and Biological Structure
- **Objective:** An automated system for manipulating the X-ray diffraction properties of protein crystals..
- Sponsor: National Institutes of Health
  Funding: $100K/year to ME



ME Core-Competency

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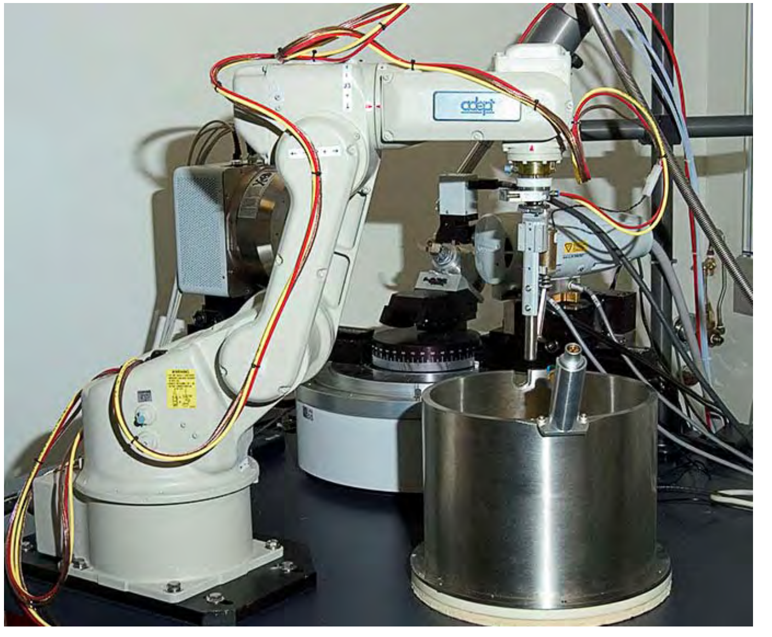

Control System A

Control of a single system (e.g., Robot) is well studied

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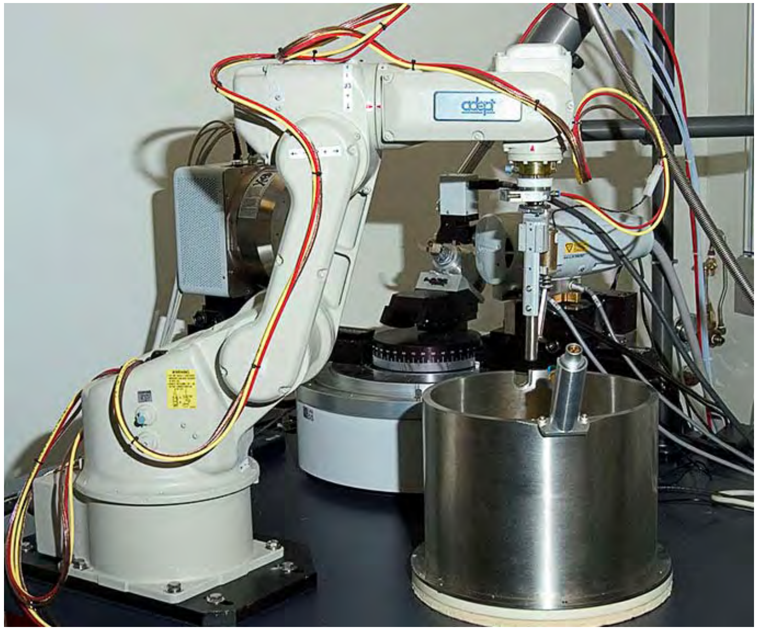


Control System A

Control System B

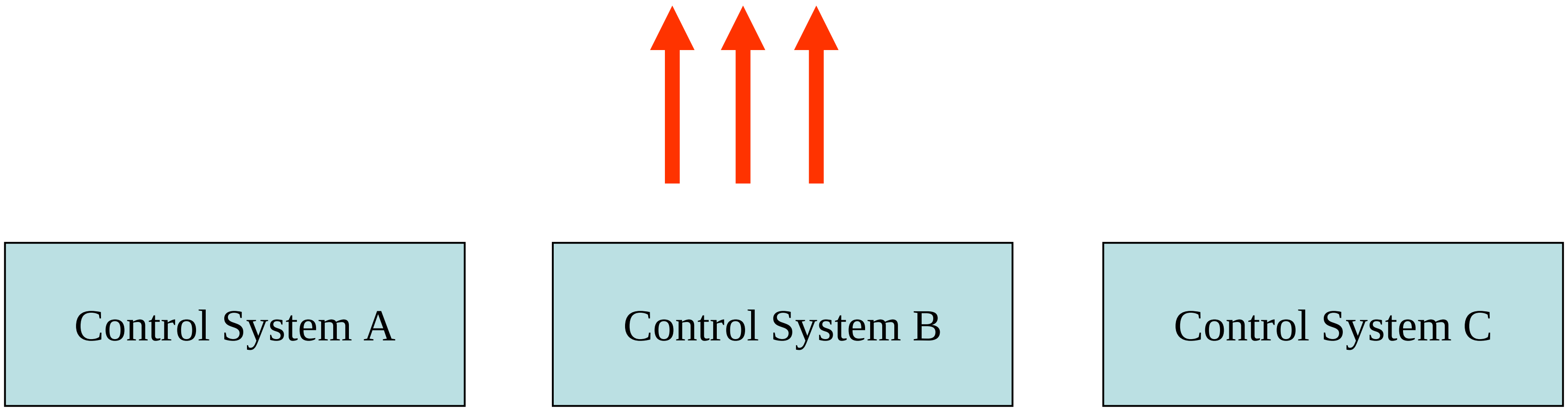
Control System C

Control of multiple distributed systems is still challenging

Leads to research in distributed systems

Supervisory Control of Distributed Systems (Prof. Martin Berg)

Similar Challenges arise in Modeling of Distributed Biological Networks (Prof. Ping Ao)



Control of a multiple distributed system is still challenging

Detailed Example 2/3

Nano-Bio-Imaging
and
Nano-Bio-Fluidics

Prof. Santosh Devasia

Project 1: Nano-Bio Imaging

Goal: Nano-scale Imaging soft human cells with AFM at high speeds

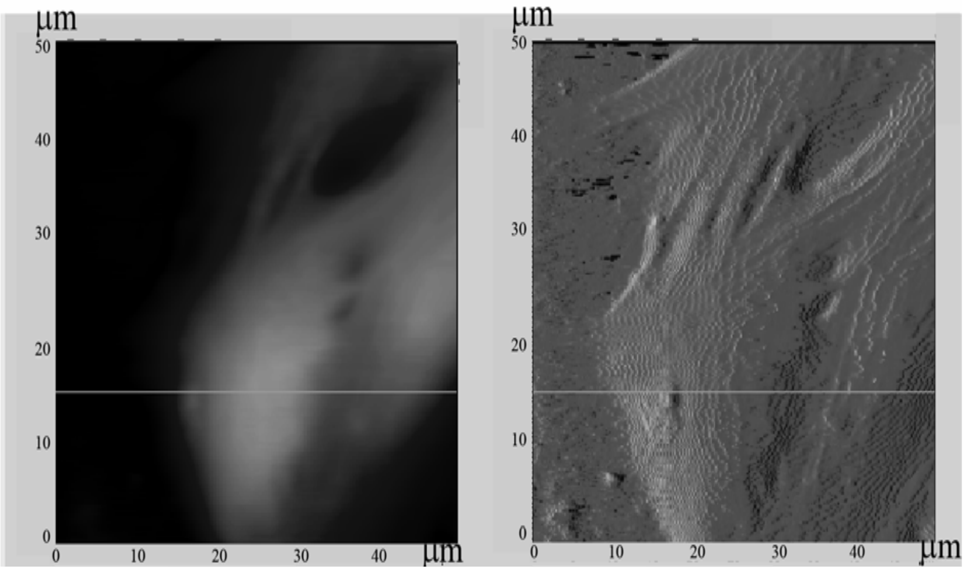
- Can we identify problems in cell migration mechanisms at the nano-scale with an AFM (**Interface of Nano and Bio**)
- Q1. How does the dimension change over time?
- Q2. How does the mechanical properties of the cell change over time?

Research Issues are related to ME core-competency

- Small forces to prevent cell damage (Controls, vibrations)
- Precision positioning
- Piezo-actuators (Nonlinear)

Collaboration with:

- Prof. M. Reed (Medical School)
- Helpful to obtain NIH (R21) Funding



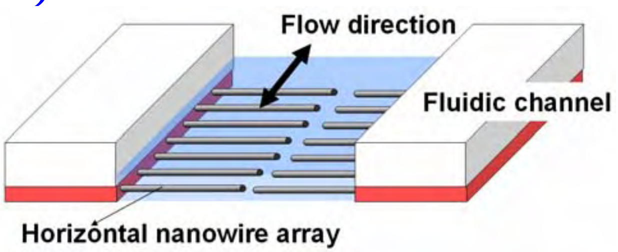
AFM images of Microvascular Endothelial Cell

Project 2: Nano/Bio-Fluidic Systems

Goal: **Move small amounts of bio-fluids**

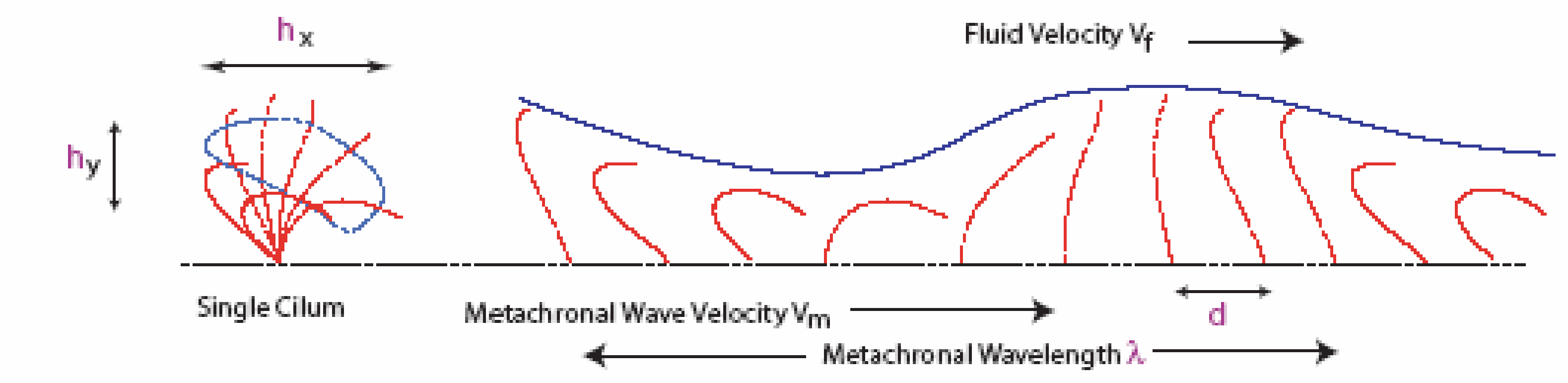
Issues: Biomimetic design (Nanowire Cilia)

- **ME Issues:**
- Micro/nano cilia-type structure (nanofabrication)
- Minimum-Energy for Portability (Controls)
- Fluid-structure interactions



Funding: Recent NSF 2006-2009 $120K/Year
Collaborators:

- **Prof. Jae Chung (ME, Nanofabrication) --**
- **Prof. Jim Riley (ME, Fluid-structure Interactions)**



Nano/Bio-Fluidic Systems

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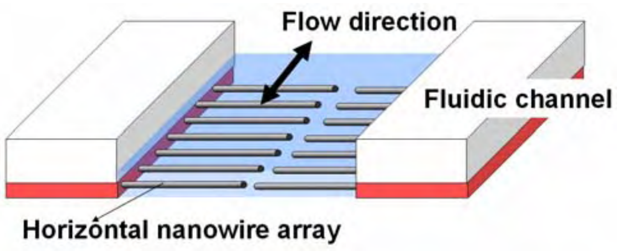

Collaborators:

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- **Prof. Jim Riley (ME, Fluid-structure Interactions)**

Example of the Multiplier Effect:

New hire in nano-manufacturing (Prof. Jae Chung)
+ Controls (Prof. Devasia) + Fluids (Prof. Riley)

Would be impossible without new hires in emerging areas

Detailed Example 3

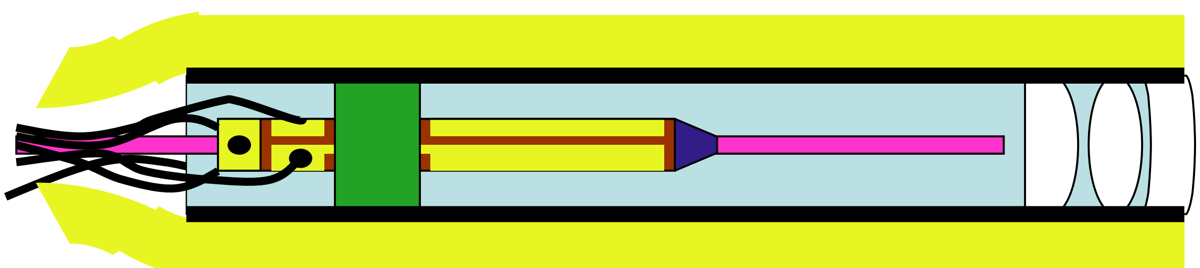
Single Fiber Endoscope

Prof. Eric Seibel

Scanning Fiber Endoscope

Idea: Rather than use "set of optical fibers to image" use a single fiber (thinner) and scan it (vibrate) to image the same area

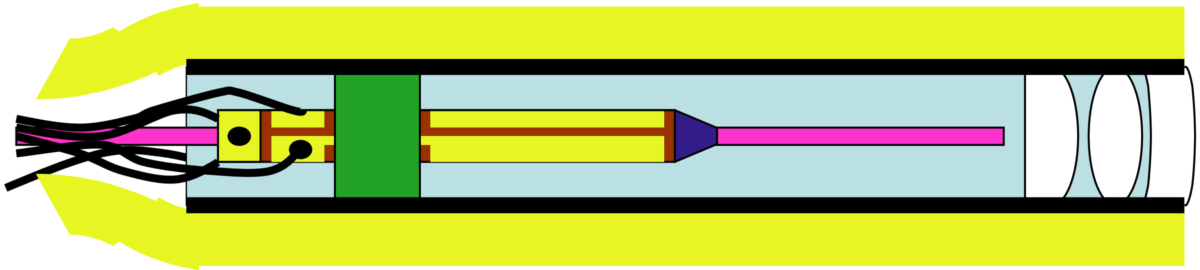
- Will lead to interventional/surgical endoscopy



1.6 mm SFE distal tip microscanner & imager

Scanning Fiber Endoscope

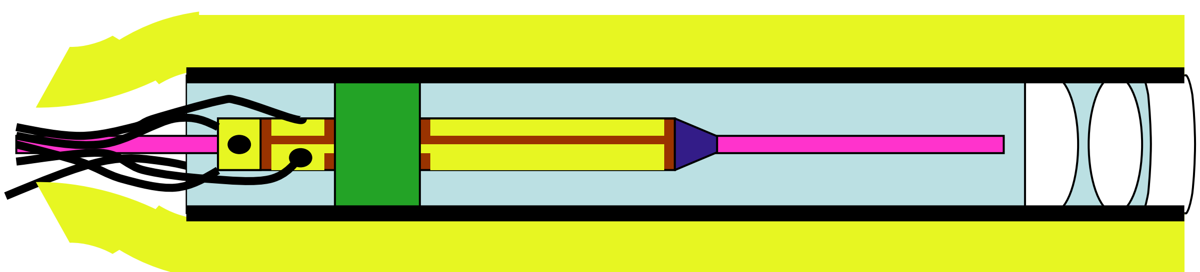
- Invented at UW (multiple patents)
- **Collaborations across UW and Med School**
  - **ME: Prof. Per Reinhall**
    (core-ME issues include: Nonlinear Vibrations, Smart materials, Controls)



1.6 mm SFE distal tip microscanner & imager

Scanning Fiber Endoscope

- Invented at UW (multiple patents)
- Collaborations across UW and Med School
  - ME: Prof. Per Reinhall
- **Expenditures for Last Year**
  - **2 NIH Grants 0.6M**
  - **PENTAX Contract: 1 M**



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Thus…Faculty are already exploiting new opportunities in Bio/Nano

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Recap: New Opportunities in Mechatronics

New Scales:

(a) Nano

New Fields

(b) Bio

Recap: Plan is to Leverage Core-ME-Competency

Mechatronics

- **Nano-scale Control**
- **Dynamics**
- **Vibrations**
- **Nonlinear Systems**
- **Robotics**
- **Instrumentation**

New Scales:
(a) Nano

New Fields
(b) Bio

Where should future focus be in Nano/Bio?

Mechatronics

- Nano-scale Control
- Dynamics
- Vibrations
- Nonlinear Systems
- Robotics
- Instrumentation

→

Potential List

a) Quantum Systems
b) Nano/Bio Manufacturing
c) Nano/Bio Instrumentation
d) Biomedical Devices
e) Distributed Systems
f) Bio-Robotics
(Rehab +Bio-mimetic)

Why These Areas?

Potential List

- Quantum Systems
- Nano/Bio Manufacturing
- Nano/Bio Instrumentation
- Biomedical Devices
- Distributed Systems
- Bio-Robotics
  (Rehab +Bio-mimetic)

Possibilities for Multiplier Effect…

Because of Multiplier Effect…

New Opportunities	ME Multipliers Core Competency	Outside Multipliers
Quantum Systems	Garbini, Devasia	Nanotech Center
Nano/Bio Manufacturing	Taya, Wei Li, Chung, Li	Nanotech Center Med School
Nano/Bio Instrumentation	Reinhall, Seibel, Devasia, Garbini	Nanotech Center Med School, Seattle VA
Biomedical Devices	Gao, Reinhall, Wang, Shen	Med School Seattle VA
Distributed Systems	Ping Ao, Berg	EE and Aero Depts Med School
Bio-Robotics (Rehab +Bio-mimetic)	Berg, Fabien, Devasia, Reinhall	EE Dept, Seattle VA Med School

Summary
Mechatronics

Opportunities	Multipliers	Future Focus

(a) New Scales
Nano

(b) New Fields
Bio

ME Core Competency

Nanotech Center

UW Medical School

Seattle VA

- **Quantum Systems**
- **Nano/Bio Manufacturing**
- **Nano/Bio Instrumentation**
- **Biomedical Devices**
- **Distributed Systems**
- **Bio-Robotics**
  (Rehab +Bio-mimetic)