Robotics & Automation: Opportunities and Challenges

Kamal Youcef-Toumi

Professor

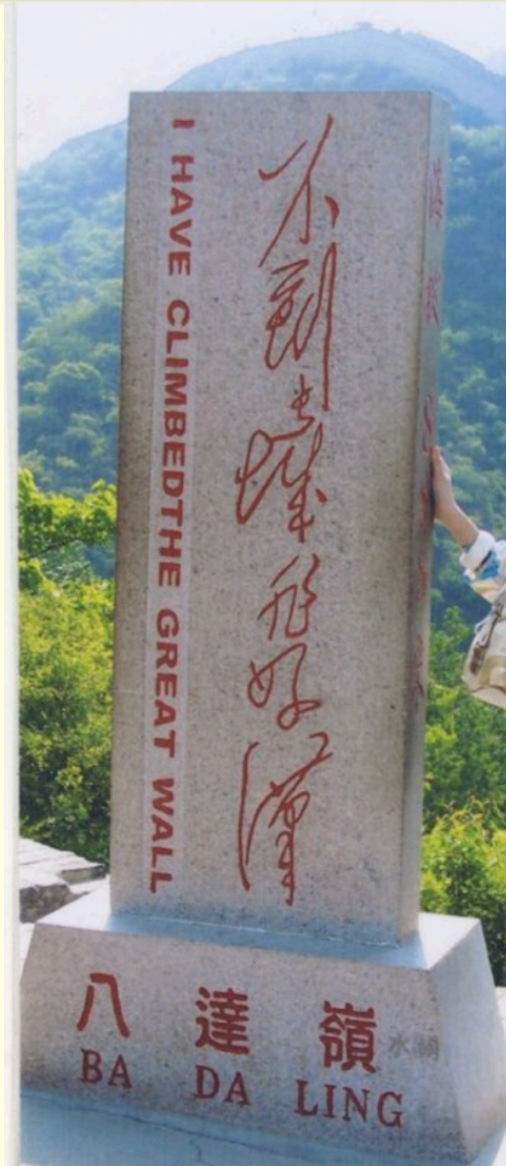Mechanical Engineering Department

Massachusetts Institute of Technology..

2017 MIT China Conference

October, 2017

Shanghai, China

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1

I am a True Man !

August 2016

2

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Mechatronics Research Laboratory @ MIT

who we are and what we do

- Research and development in:
  - **System dynamics, modeling, Simulation & Design**
  - **Instrumentation,**
  - **Control systems**
- With applications to
  - **Robotics and**
  - **Automation**.

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Some of our Collaborators ...

ShinMaywa

TOSHIBA
Leading Innovation »»»

MARS
incorporated

Panasonic®

JSW
THE JAPAN STEEL WORKS, LTD.

Synfuels

Wuxi Friedrich Measurement & Control Instruments Co.

Schlumberger

OMRON
Sensing tomorrow™

Banzan
Client Centric Responsive Innovation

TOYOTA

Qatar Foundation

NASA
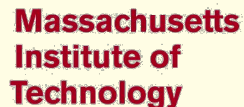
National Science Foundation

DENSO

EBARA

SAMSUNG

DAEWOO

MITSUBISHI ELECTRIC

IBM®

Gillette®

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4 Key Trends

4 Key Trends

World's changing societies

Increase in number of companies

Growing Population
Aging
Urbanization
Highly educated

Needs
Opportunities
Innovation

4 Key Trends

World's changing societies

Productivity Efficiency Quality
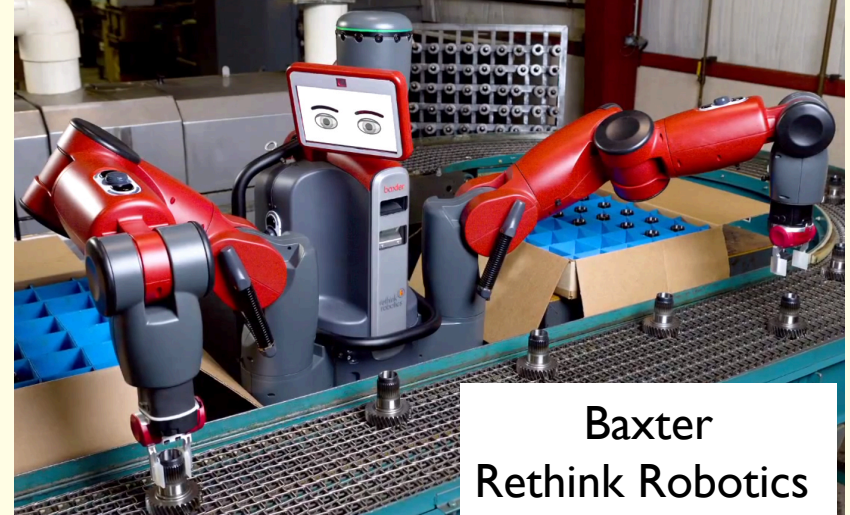
Increase in number of companies

Labor Cost

- **Advances in Fundamentals, Technology & Innovation**

- **Limitations**

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Significant Advances in Robotic Applications

IBM Watson

Da Vinci - Intuitive Surgical

Google self driving car

Baxter
Rethink Robotics

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Due to Advances in Fundamentals & Technological Innovations

Instrumentation

- Sensory Systems - Computer Vision
- Actuation Systems
- Manipulation Devices
- High Performance Interfaces

...

Computing

- Control Systems
- Planning and Scheduling
- Optimization
- Machine Learning

...

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Some of Today's areas of focus

- **Dexterity and precision**

- **Versatility**

- **Collaborative operations**

- **...**

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Milestones & Enablers

Towards the Future ...

Milestones

- High speed manipulation
- Human-like intelligence
- Collaborative intelligence
- Self awareness
- Integrated robot design
  ...

Enablers

- Distributed instrumentation
- High speed adaptive/learning control
- Development platforms
- Sensor networks
- Integrated design methodologies
- Manufacturing techniques
  - ...

High Speed Manipulation Design

1. High Speed Manipulation: Enablers

Distributed sensing and actuation

- Control local properties of material
- Smart material with built-in instrumentation
- Similar to pixels in TVs

Below 8°C
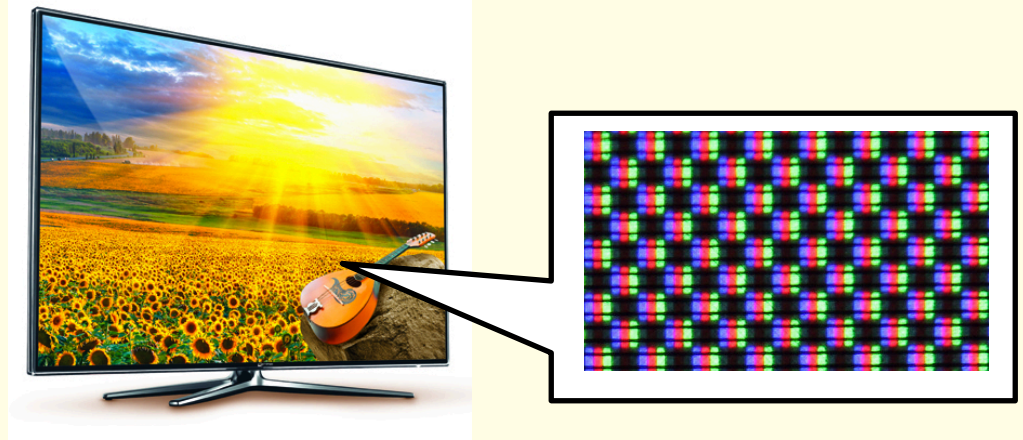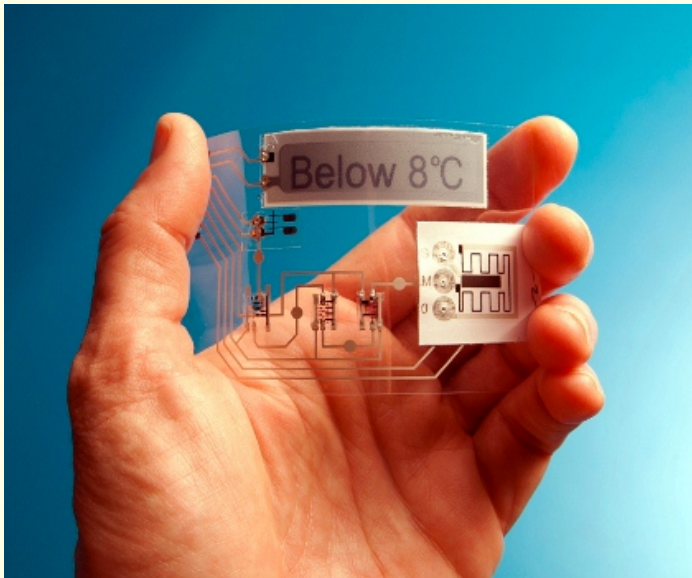
image courtesy of ndtv.com, cnet.com, mbtimetraveler.com

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Soft robotics

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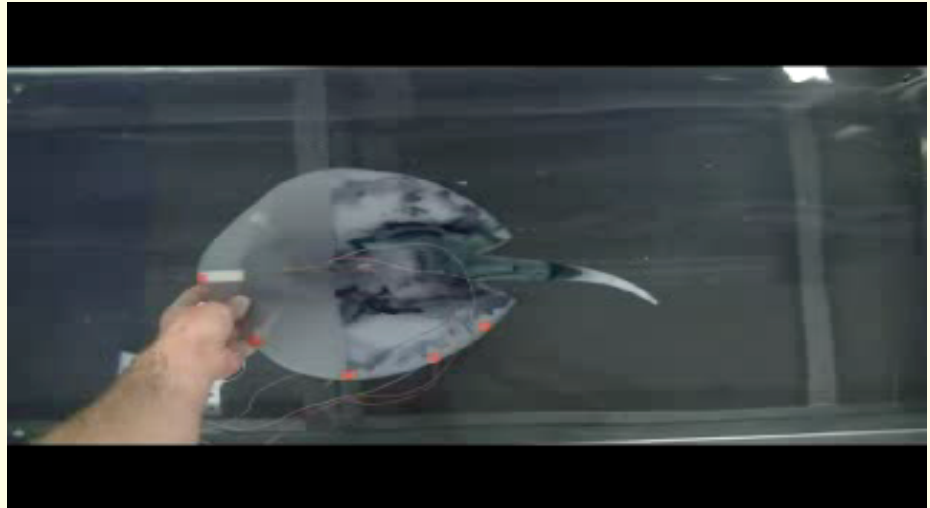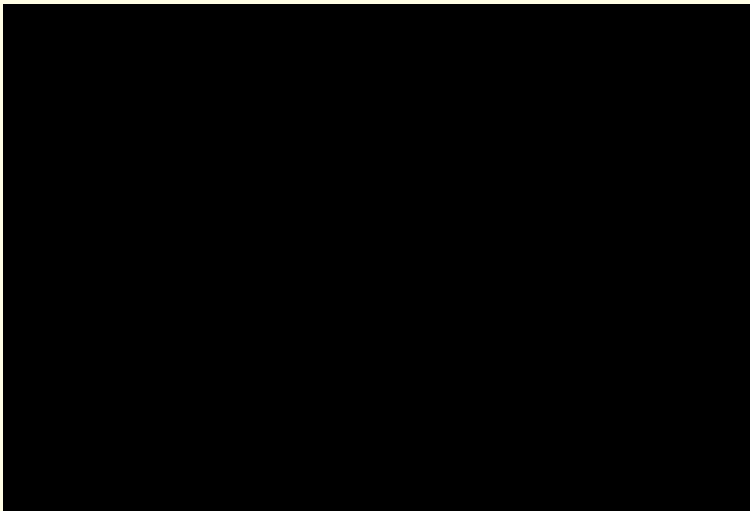
Design Methodologies

- Approach 1: Curve fitting.

- Constraints:

$$M, \ldots, l \longrightarrow \boxed{\textit{Models of Fish Tails}} \longrightarrow h(x,t)$$
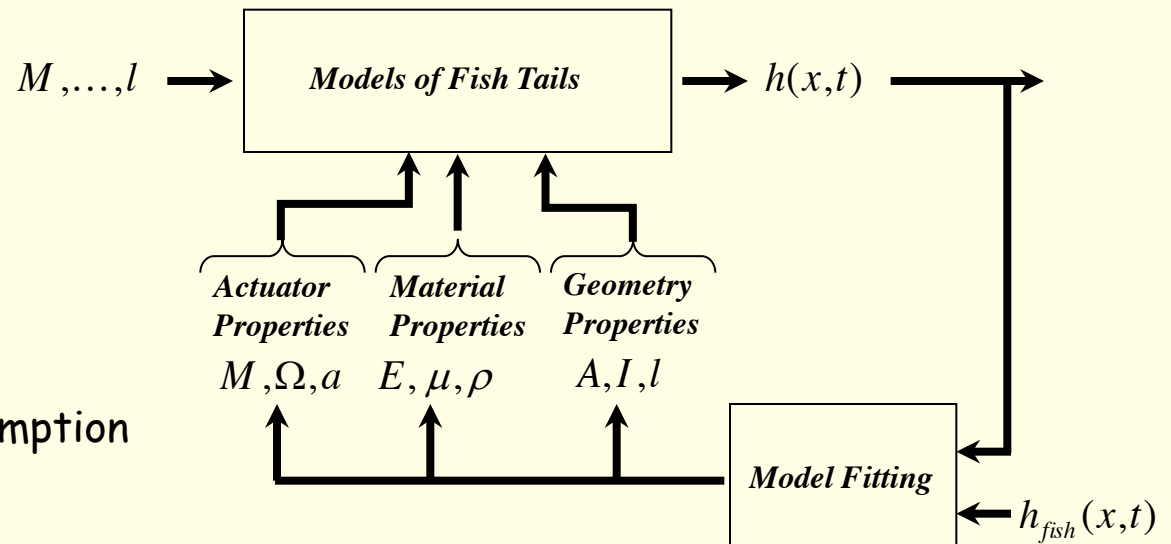
- Minimize power consumption

$$\underbrace{\begin{array}{c}\textit{Actuator}\\\textit{Properties}\\ M, \Omega, a\end{array}}\quad \underbrace{\begin{array}{c}\textit{Material}\\\textit{Properties}\\ E, \mu, \rho\end{array}}\quad \underbrace{\begin{array}{c}\textit{Geometry}\\\textit{Properties}\\ A, I, l\end{array}}$$

$$\boxed{\textit{Model Fitting}}$$

$$h_{fish}(x,t)$$

$$I = I_{fish}, \Omega = \omega, A = A_{fish}, \rho = \rho_{liquid}, m = m_{liquid}, l = l_{fish}$$

$$\min\left(\left\| h_{fish} - h \right\|^2 \right)$$

$$\nabla P_r = \nabla M \dot{h}'_a = 0$$

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Prototype designs and Fabrication

- Casting

(a)   (b)

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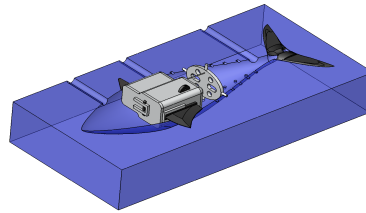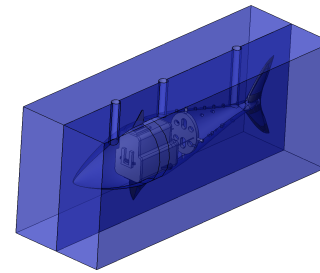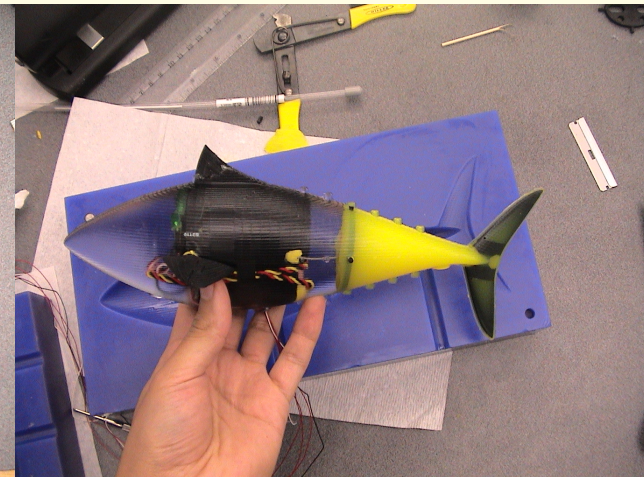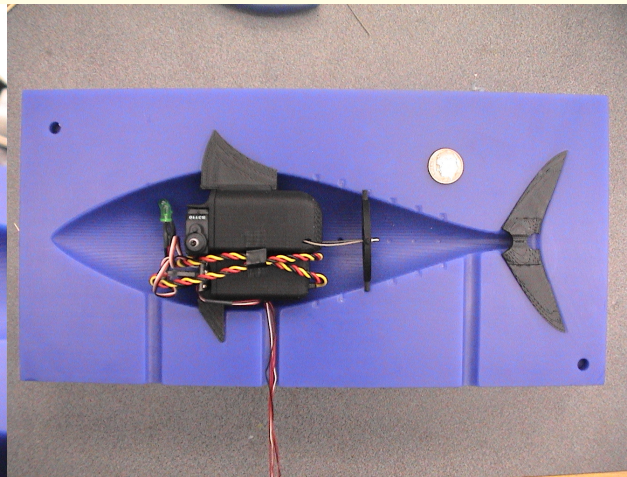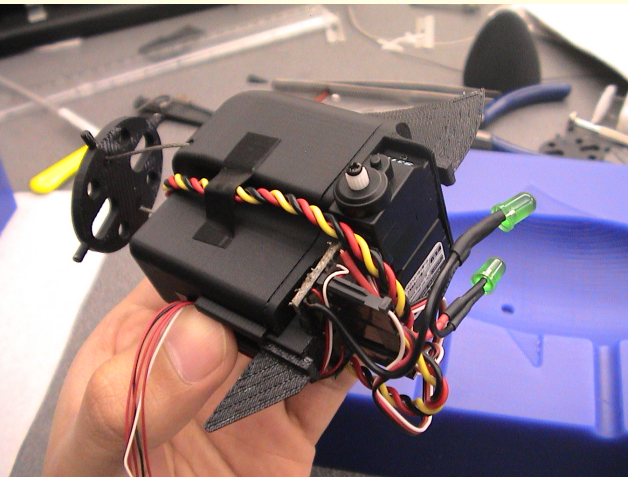
Prototype designs and Fabrication

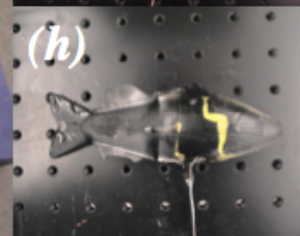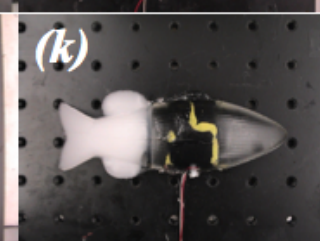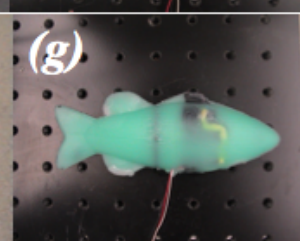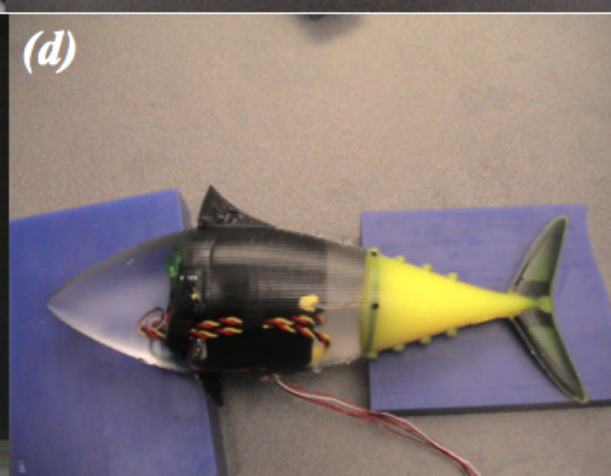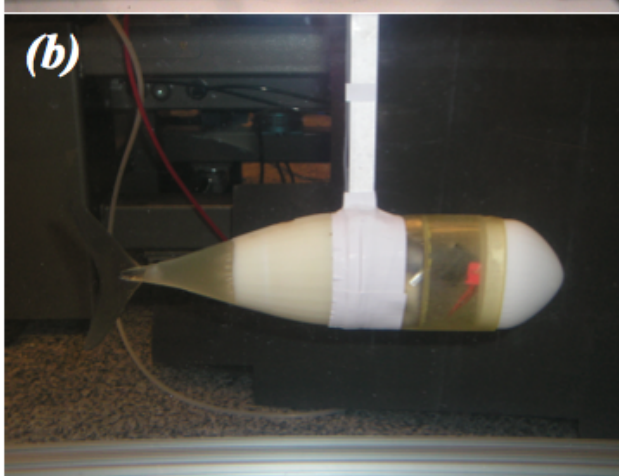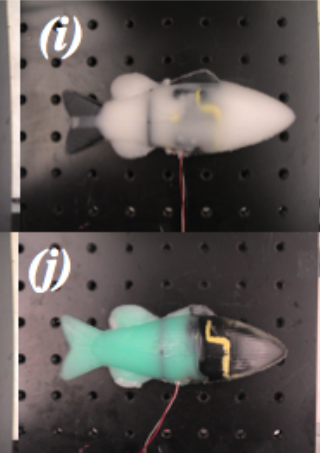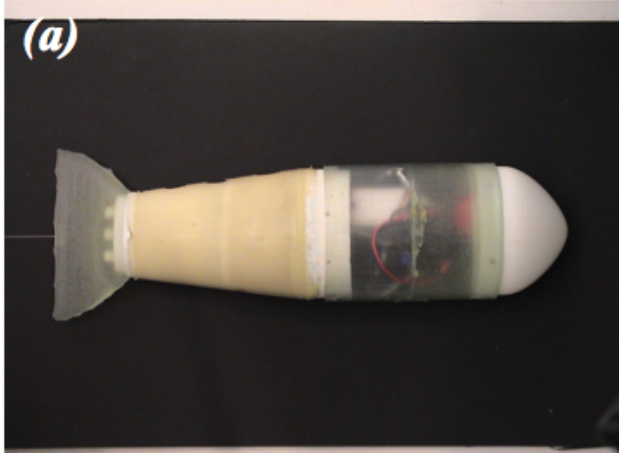# High Speed Manipulation Control
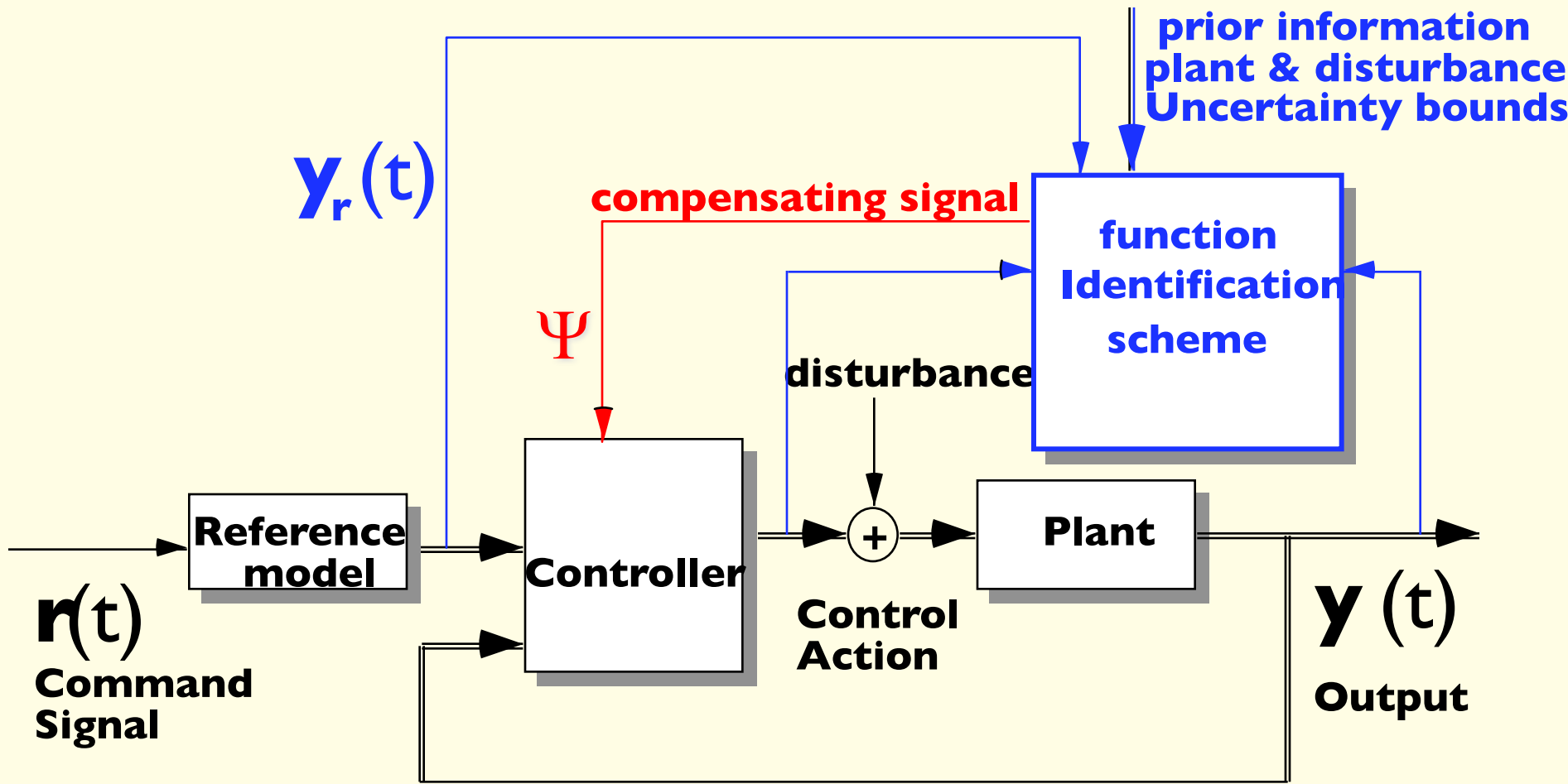
Control of Robot Manipulators

- **Robustness**
  - Parameter uncertainties
  - Structural uncertainties
  - Disturbances
  - ...
- **Guarantees**
  - Stability
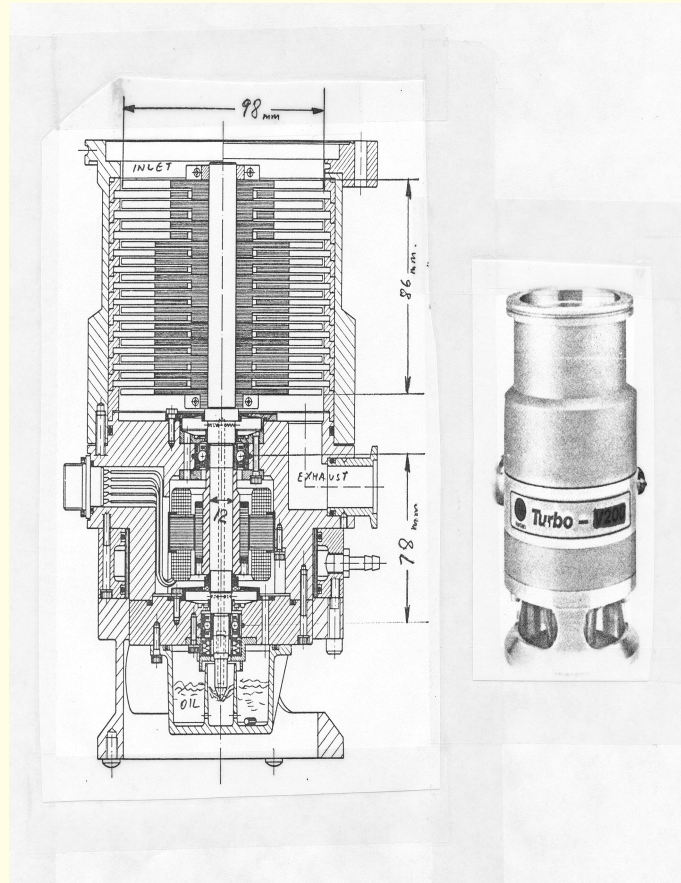 - Performance
  - ...
- **High speed real time**
  - ...

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Control System Architecture – Direct Rapid Adaptive Control with Function Estimation

Time delay control system

prior information
plant & disturbance
Uncertainty bounds

$y_r(t)$

compensating signal

function Identification scheme

Ψ

disturbance

Reference model

Controller

Plant

$r(t)$
Command Signal

Control Action

$y(t)$
Output

Identification scheme: Convolutions, …

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High Speed & High Precision Magnetically Levitated Systems

X_1, X_2, Z : bearing local cooridinates

Gravity

X_1

c.g.

X_2

Radial bearings

Axial bearing

Z

Turbo-molecular pump

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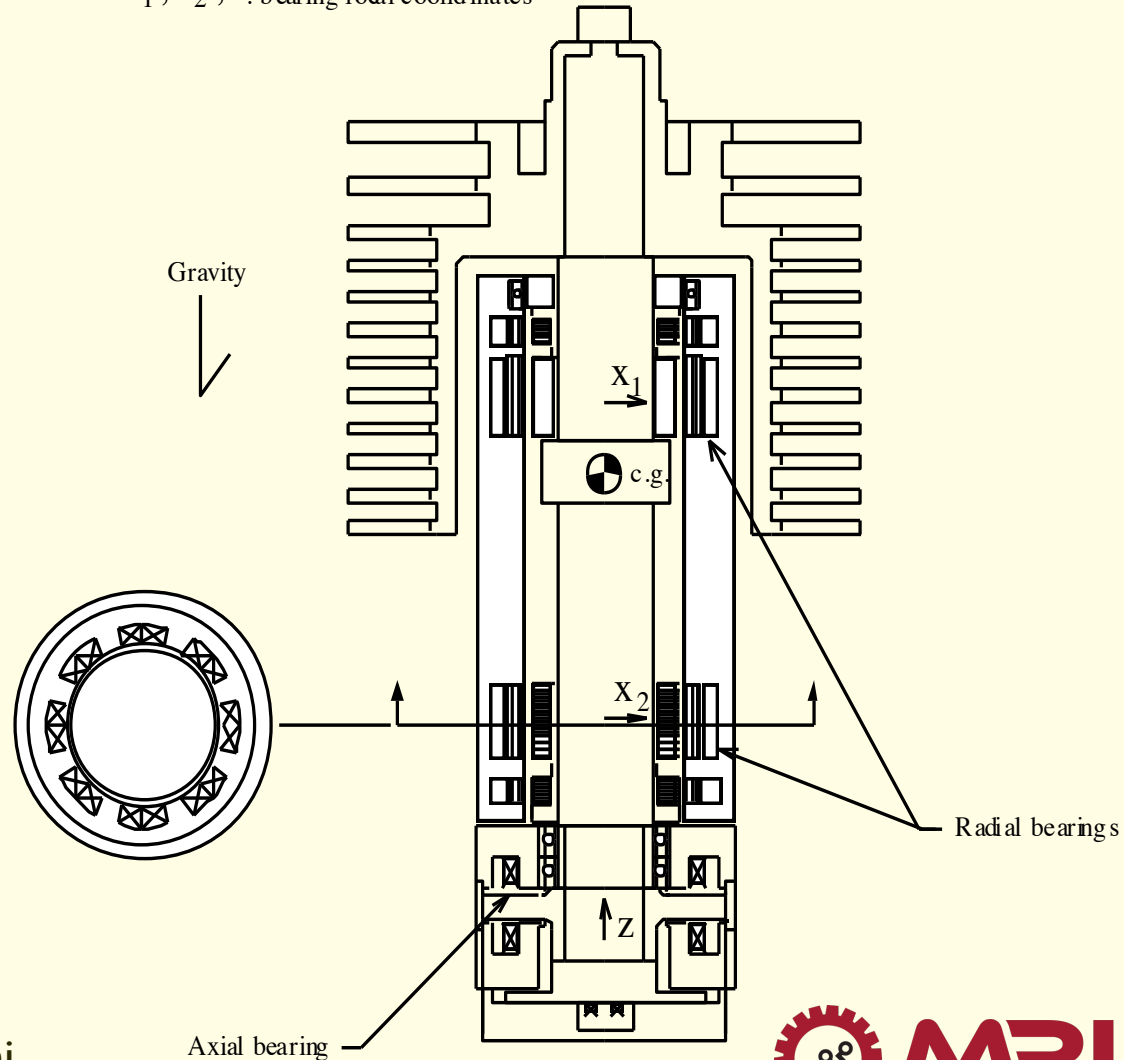
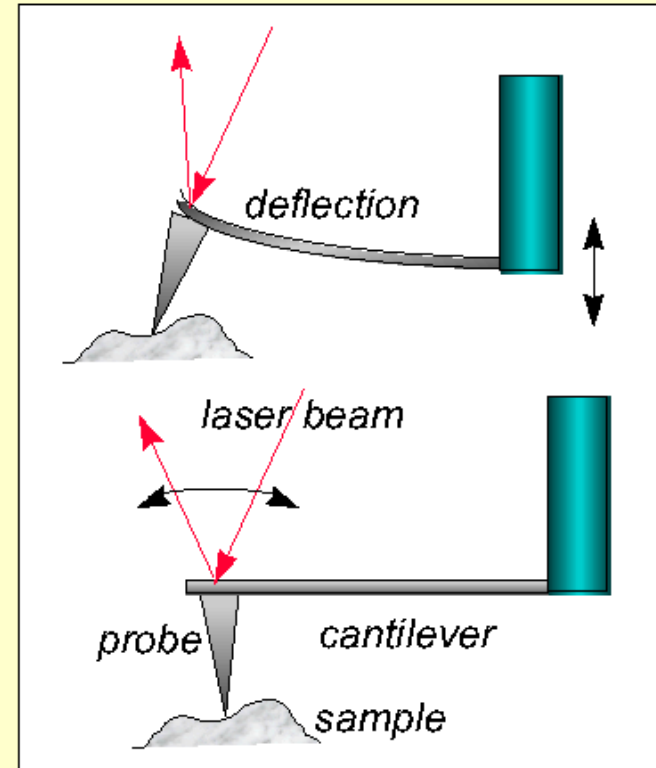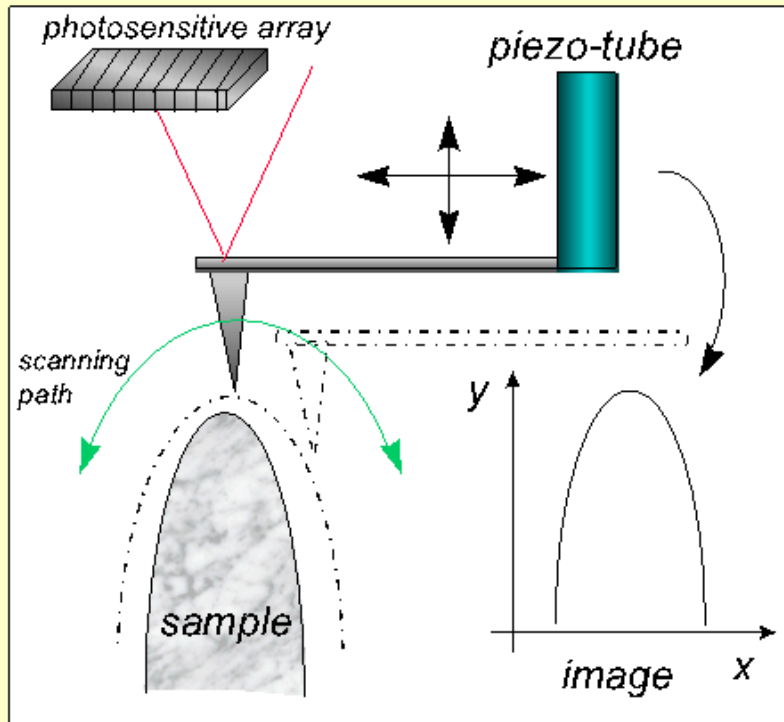# High Speed & High Precision Magnetically Levitated Systems
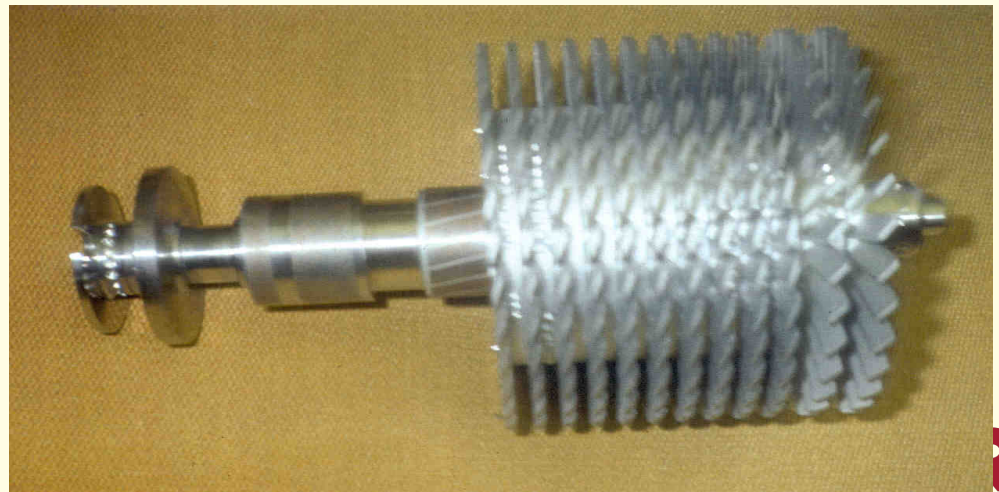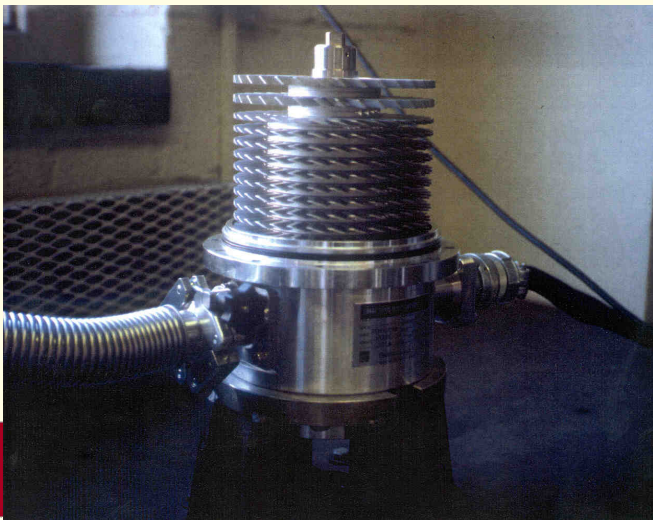
Nanoscale High Speed Imaging

High Speed Nano-Scale Video Imaging

- Conventional scanning rate : few lines/second
- MIT scanning rate: ~ 4000 lines/second
  20M samples/second

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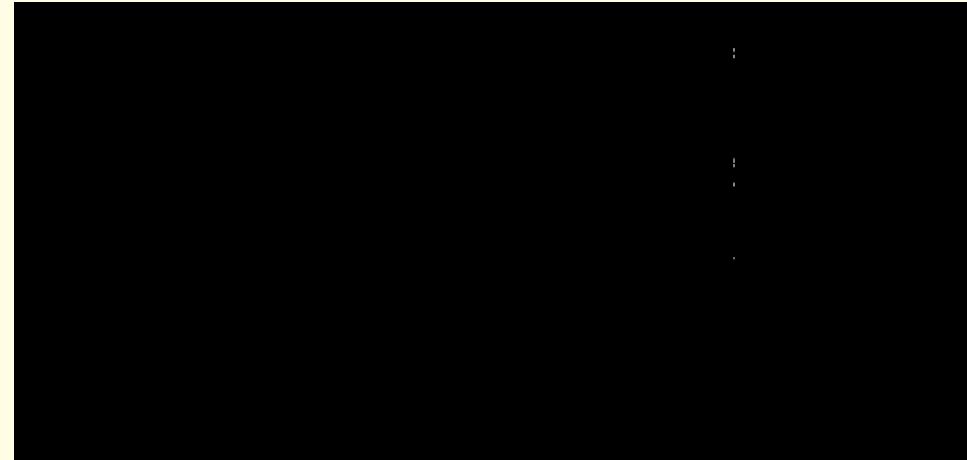MECHATRONICS RESEARCH LABORATORY
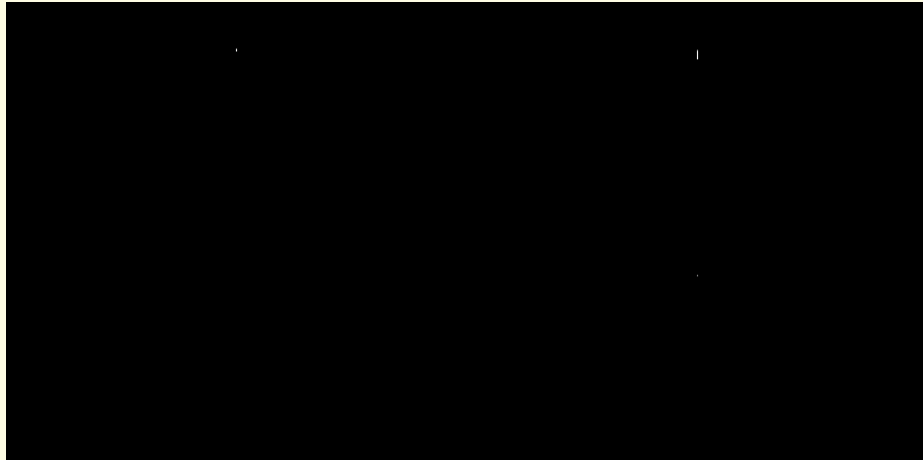
High Speed Nano-Scale Video Imaging

Acid induced retreat of calcite layers

Etching of calcite – no initial pits

Formation and deepening of pits in calcite
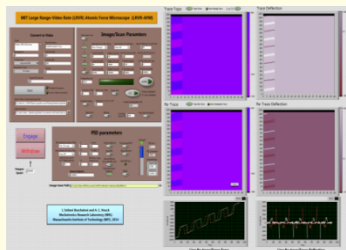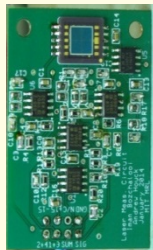
Deposition and stripping of copper on gold
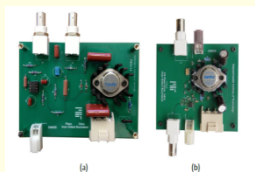
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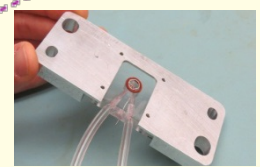
High Speed Nano-Scale Video Imaging

Photodiode Circuitry

20 MHz Imaging Throughput

Power Amplifier (1 MHz)

Camera
1
2 Tube Lens
Beam Splitter
4
Laser
3
5 Illuminator
Photodiode
6
8 Dichroic Mirror
7 Polarizing Beam Splitter
9 λ/4 plate
10 Objective
Flexure Diaphragm
Piezo Stack
Z_2
X_2
Z_1
Multi-Actuated Scanner
X_1
Y

3.5 μm laser spot

15 mm sample stage

Z_2
X_2
Z_1
X_1
Y

Fluid Cell
Liquid in/out

Cantilever Holder

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Human-like Intelligence

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Human-Like Intelligence

Understanding the scene
Example: **picking** the right item
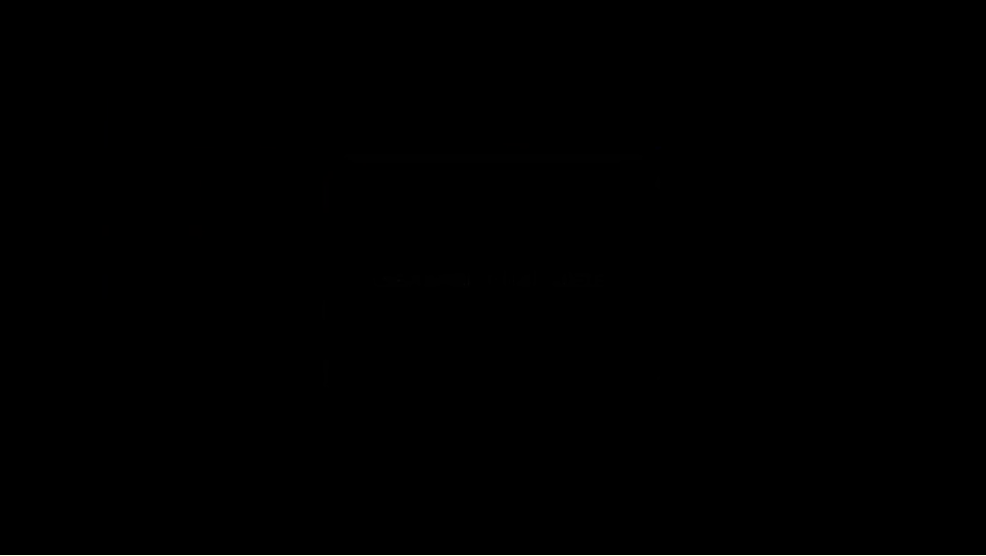
Making judgment and decisions
Example: **packing** in the right size box

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Human-Like Intelligence

- Learn by watching
- Teach other robots
- Cooperate with human operators and Robots
- And …

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Human-Like Intelligence

- And …
- Correct/Assure accomplishing of tasks

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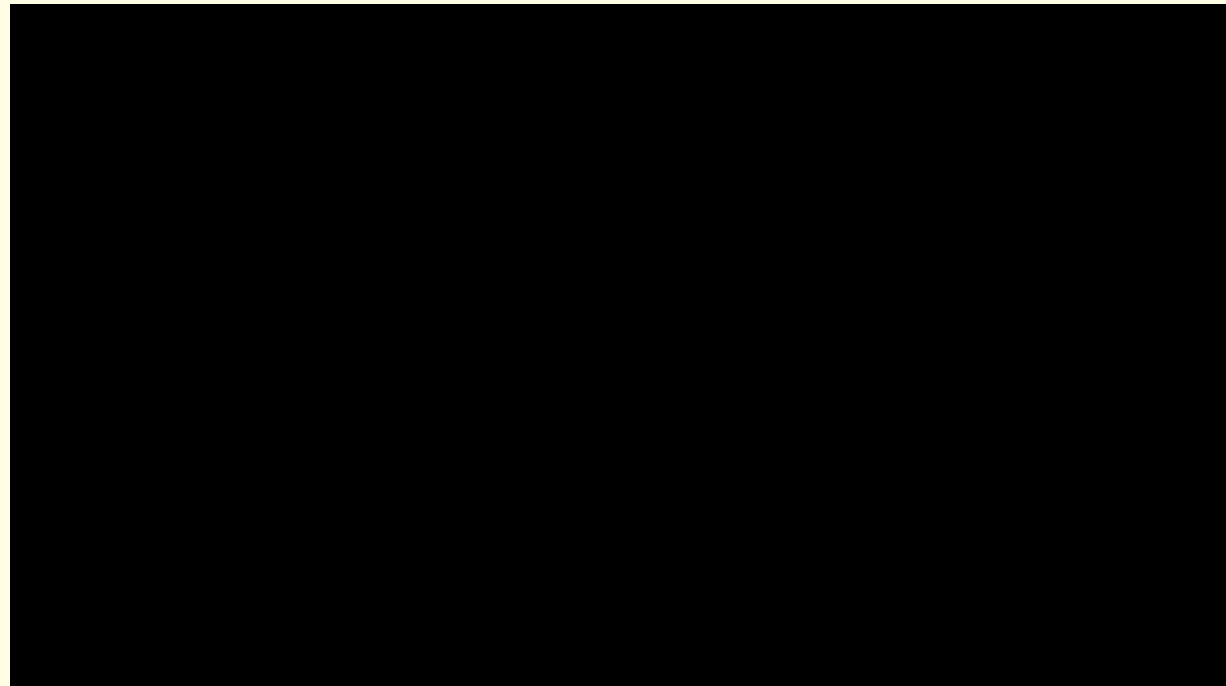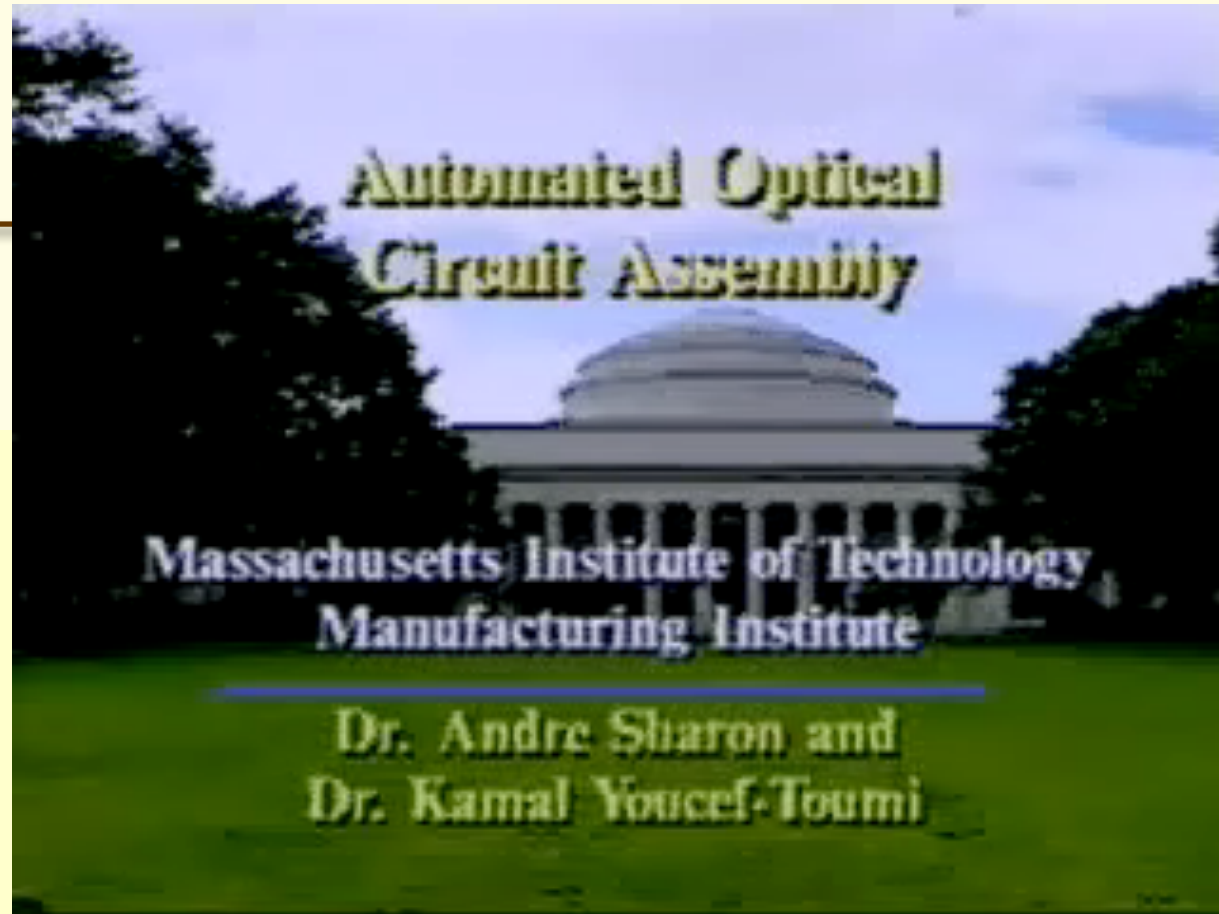
Multi-Agent: Control by Objective …

- Distributed intelligence & multi-agent systems

- Improved control and system flexibility

- …

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Multi-Agent: Control by Objective ...

- Stripping
- Cleaning
- Cleaving
- Splicing
- Splice loss measurement
- Proof testing
- Recoating

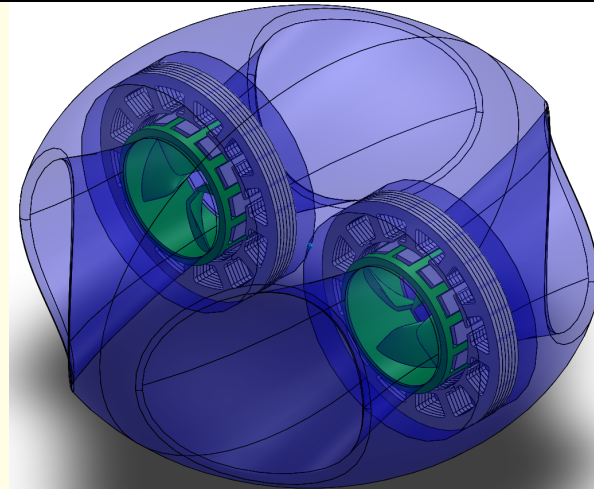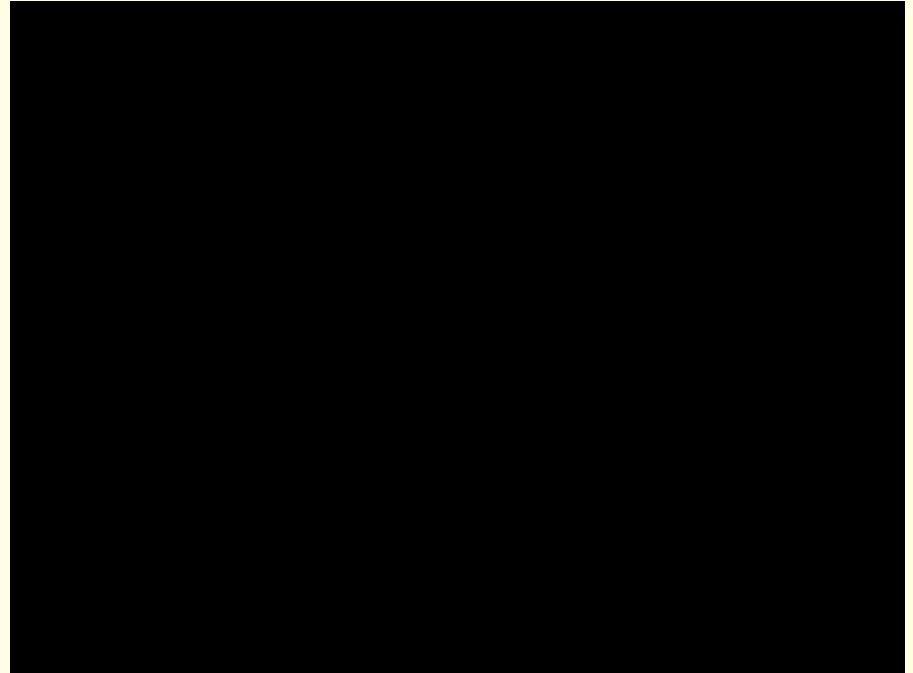**Fiber Optics & Photonics**
Automatic Optical assembly station

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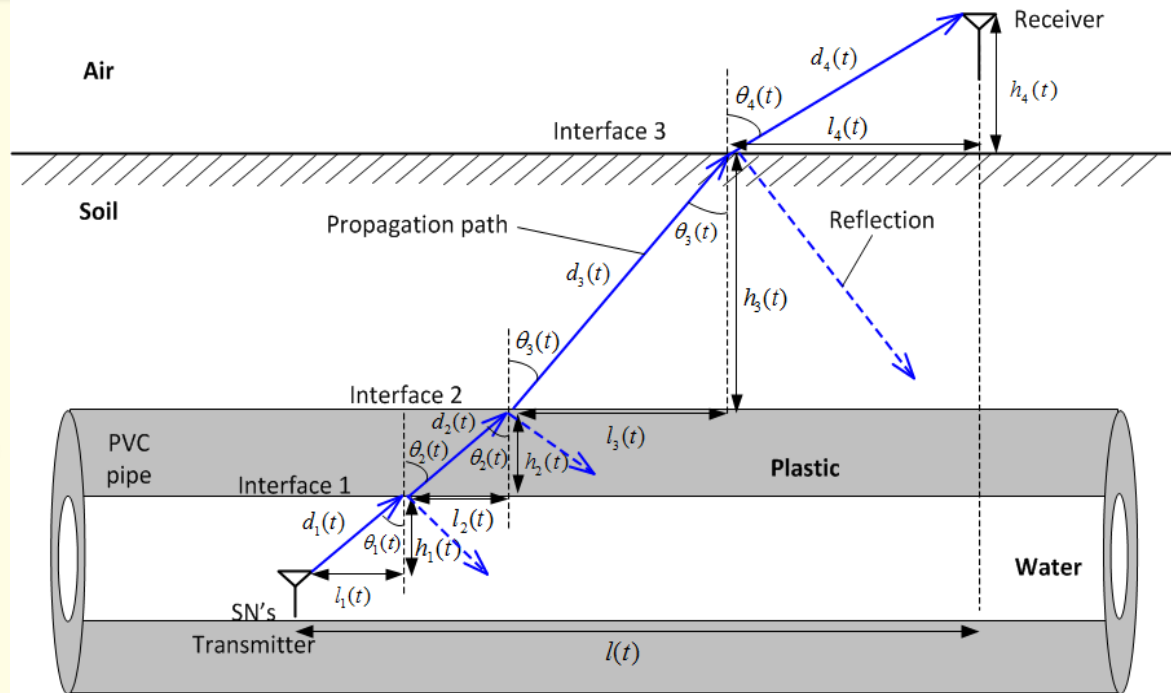MRL MECHATRONICS RESEARCH LABORATORY

Multi-Agent: Control by Objective ...

- Inspection
- Repairs
- Mapping
- …

Wireless Communication Channel Modeling

- Path loss model
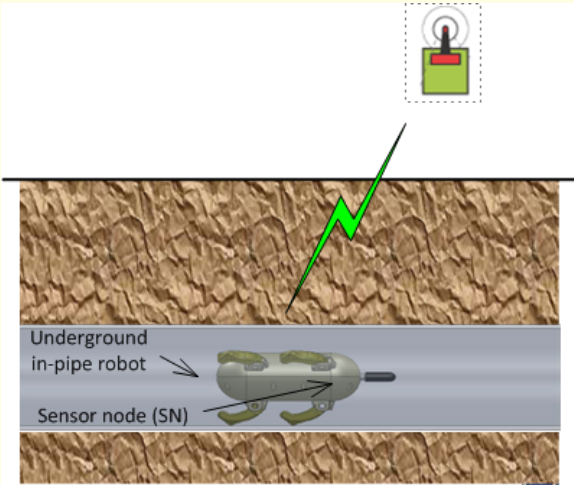
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

$$\frac{\sin\theta_2}{\sin\theta_3} = \frac{n_3}{n_2}$$

$$\frac{\sin\theta_3}{\sin\theta_4} = \frac{n_4}{n_3}$$

$$L_p^{\text{tot}} = L_p^1 + L_p^2 + L_p^3 + L_p^4 + L_R^{1|2} + L_R^{2|3} + L_R^{3|4}$$

$$P_R(\text{dBW}) = P_T(\text{dBW}) + G_R(\text{dB}) + G_T(\text{dB}) - L_p^{\text{tot}}(\text{dB})$$

$$h_1\tan\theta_1 + h_2\tan\theta_2 + h_3\tan\theta_3 + h_4\tan\theta_4 = l$$

Communication and Robot Localization
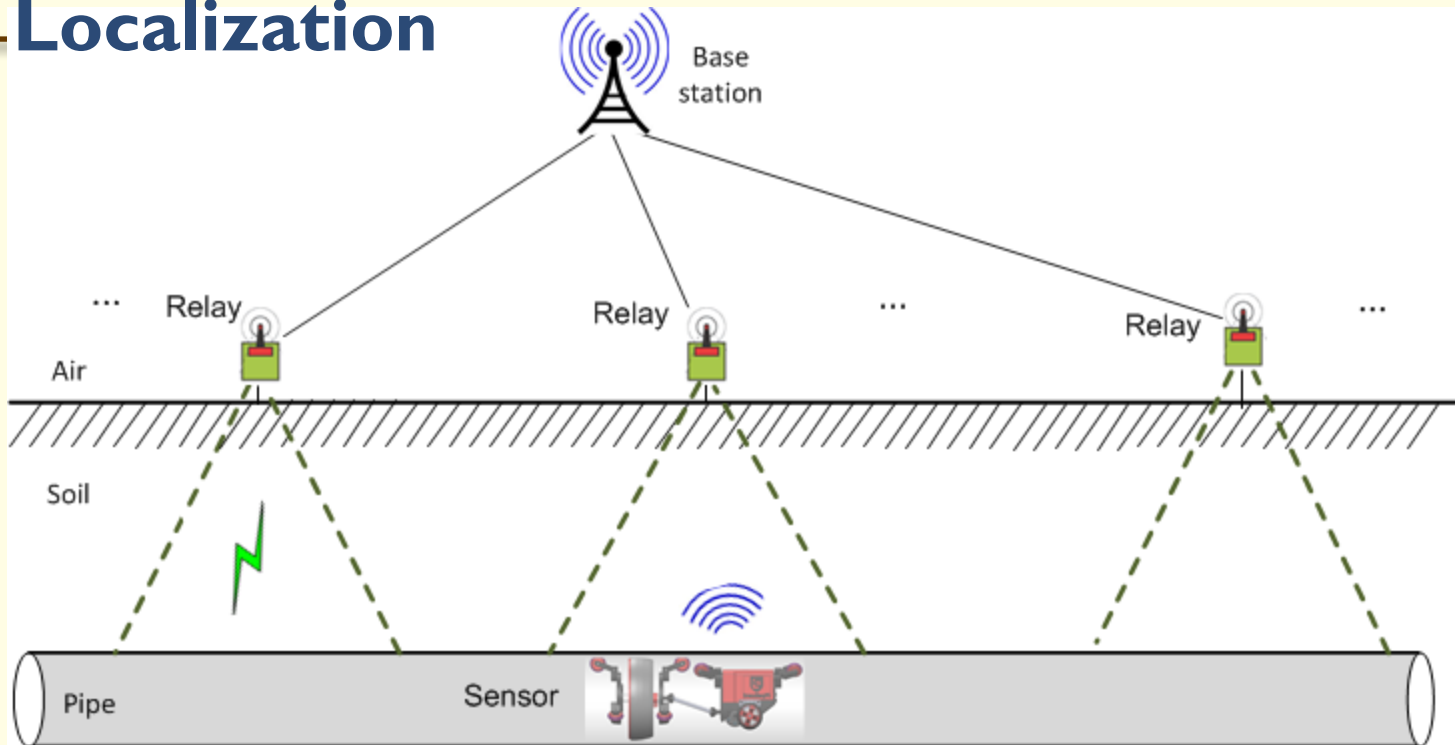

- **Two-way communications through relays:**
  - ✓ Base station to sensor
  - ✓ Sensor to base station

- **Deployment of aboveground relays can be used for**
  - ✓ Improvement of wireless communications
  - ✓ Reduction of the sensor's power on communications
  - ✓ Localization of the sensor

Communication & Robot/Defect Localization
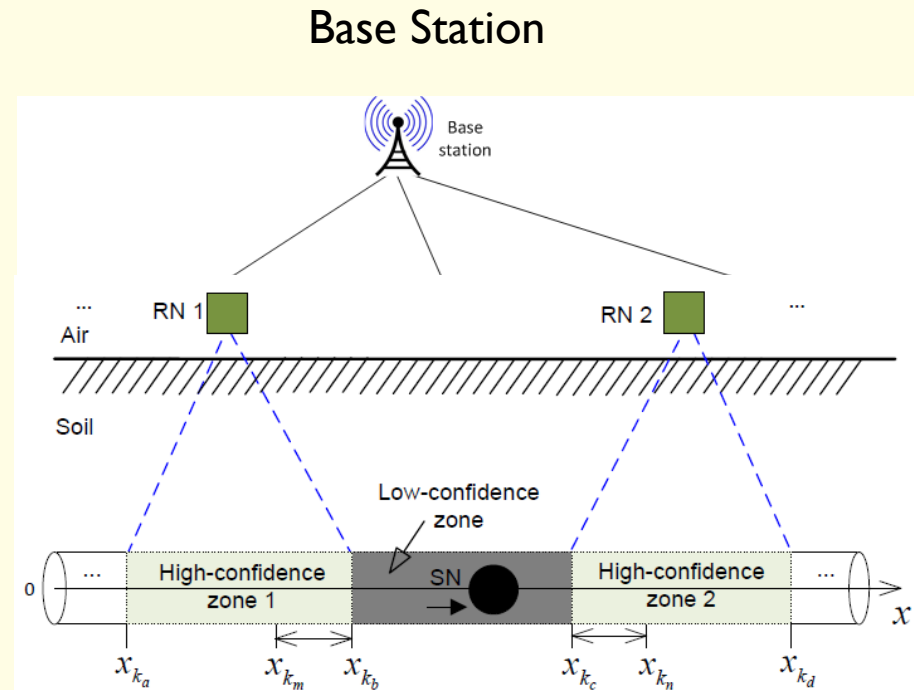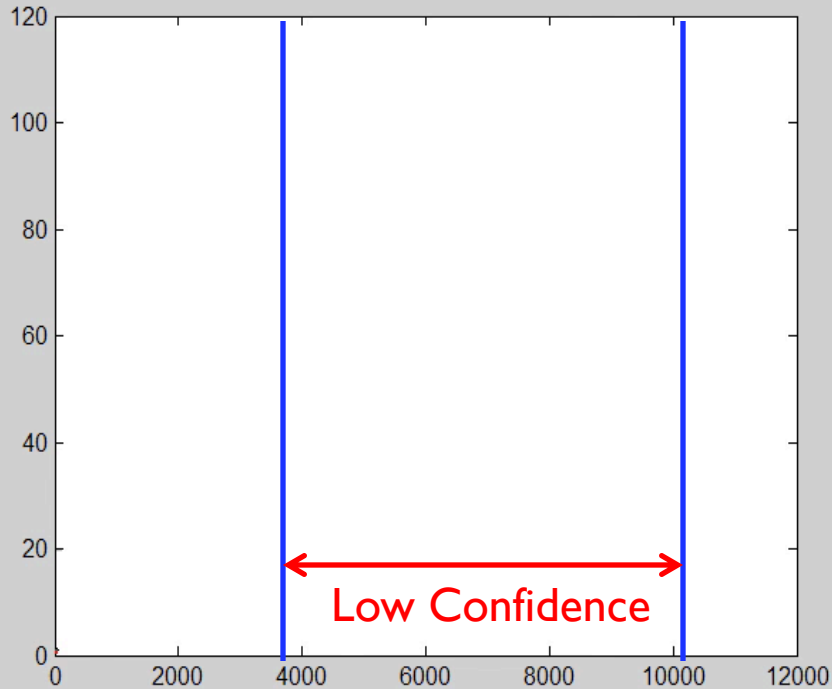
- Localization results in the low-confidence zone can be improved by the localization results in neighboring high-confidence zones.

Self-Awareness

Learning and Intelligent Systems

- Validation
- Regularization
- Classification
- Prediction
- Feature selection/sparsity,
- Feature learning
- Unsupervised learning:
- Modelling: Probabilistic, Discriminative vs. generative models, time series, Markov etc...

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Self Awareness

- Moving targets
  - Intercepting
  - Tracking

- Minimizing Mean Time To Repair (Mean Time To Repair < 1mn)
- Instant reconfiguration

- Multiprocessor
- Time optimal
- Modular

Factory Automation – Handling product in Motion Palletizing robot

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Self-Awareness: Future

- Determine current performance
- Predict future performance
- Realize through sensor networks & intelligence
- Prognosis ensures robustness

System says you should retire. I am here to replace you.

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Self-Awareness: Future

System says you should retire. I am here to replace you.

Great Future

Image courtesy of Michui Kaku

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Thank You.

谢谢

youcef@mit.edu

http://mechatronics.mit.edu/

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