Emerging Frontiers in Robotics and Smart Systems

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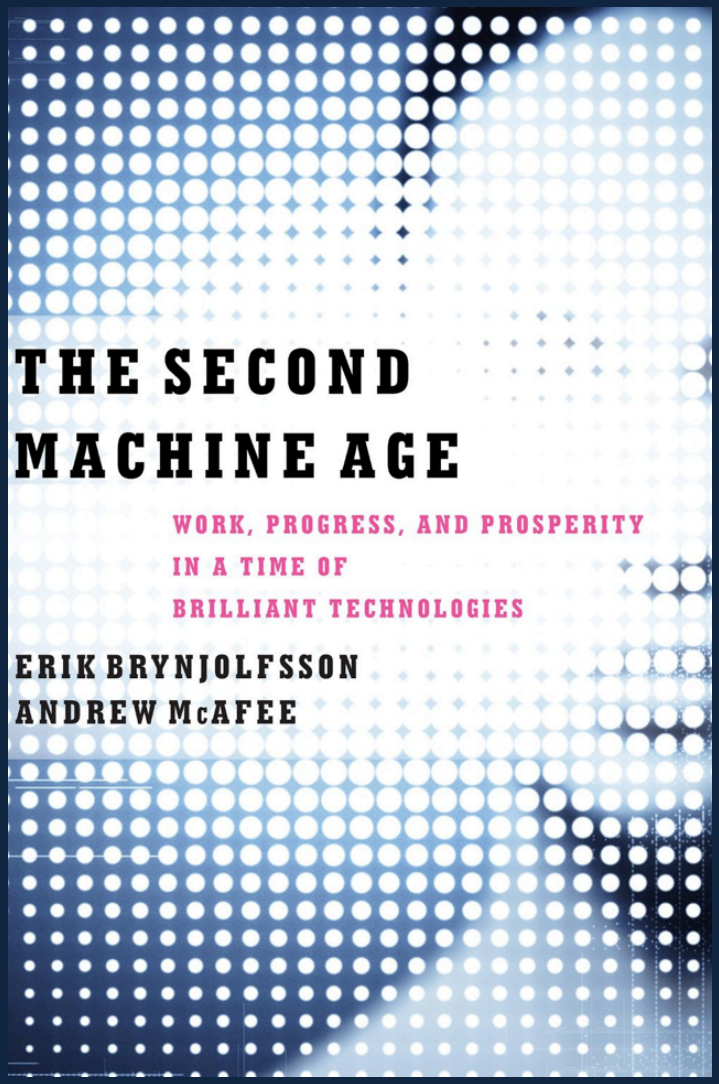
National Science Foundation

Presentation at the US Naval Academy
November 4, 2014

An Inflection Point: The Second Machine Age

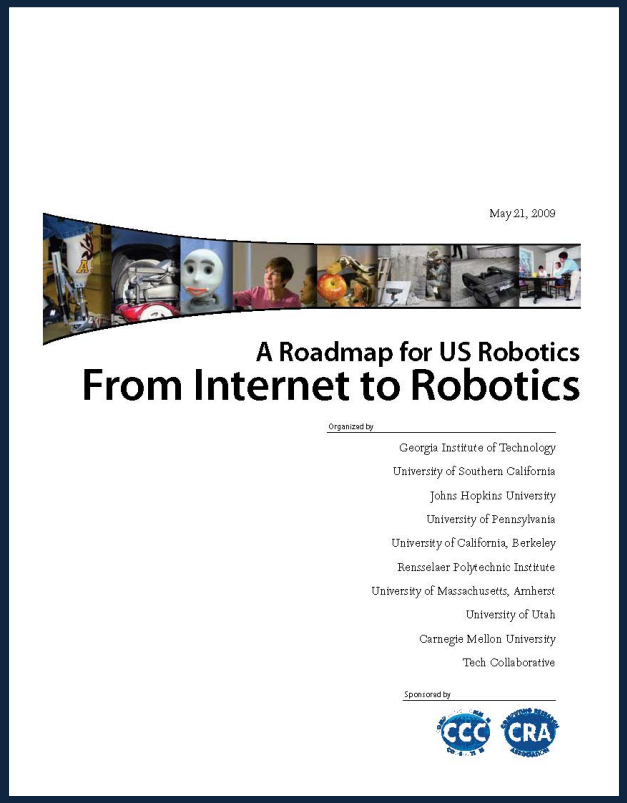
- Conventional wisdom: “Computers are good at following rules … but bad at pattern recognition.”
- Over the last ten years:
  - Self-serving cars
  - Brain-machine interfaces
  - Face recognition
  - Language translation
  - Watson and Jeopardy
  - Robotics and deep inroads against Moravec’s Paradox
  - 3D printing and additive manufacturing



The National Robotics Initiative (NRI)

A **nationally coordinated** program across multiple government agencies to develop the **next generation of robotics**, to advance the **capability and usability** of such systems and artifacts, and to encourage existing and new communities to focus on **innovative application areas**.

United States Department of Agriculture
National Institute of Food and Agriculture



May 21, 2009

A Roadmap for US Robotics

From Internet to Robotics

Organized by

Georgia Institute of Technology
University of Southern California
Johns Hopkins University
University of Pennsylvania
University of California, Berkeley
Rensselaer Polytechnic Institute
University of Massachusetts, Amherst
University of Utah
Carnegie Mellon University
Tech Collaborative

Sponsored by

CCC CRA

http://www.us-robotics.us/reports/CCC Report.pdf

REPORT TO THE PRESIDENT AND CONGRESS

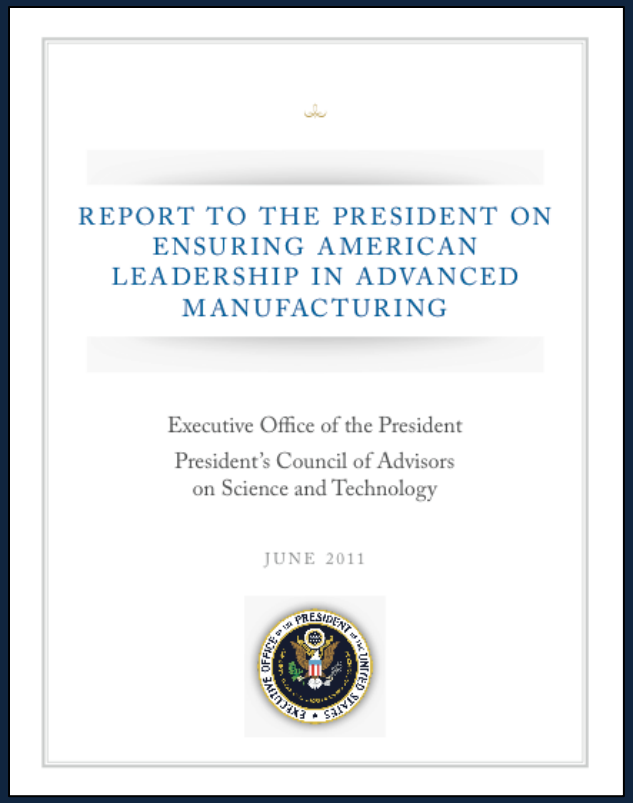
DESIGNING A DIGITAL FUTURE: FEDERALLY FUNDED RESEARCH AND DEVELOPMENT IN NETWORKING AND INFORMATION TECHNOLOGY

Executive Office of the President

President's Council of Advisors on Science and Technology

DECEMBER 2010

http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf



REPORT TO THE PRESIDENT ON ENSURING AMERICAN LEADERSHIP IN ADVANCED MANUFACTURING

Executive Office of the President

President's Council of Advisors on Science and Technology

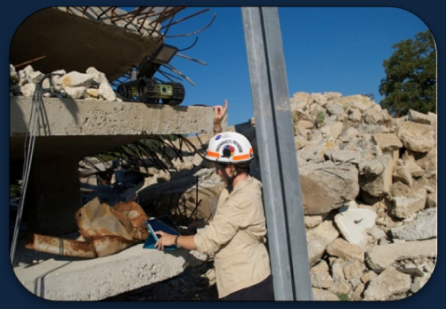
JUNE 2011

http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_amp_steering_committee_report_final_july_27_2012.pdf

NRI serves multiple key national priorities

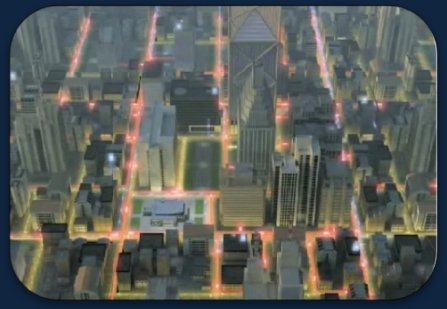
Manufacturing & Smart Systems

Agriculture



Emergency Response & Disaster Resiliency

Health & Wellbeing



Transportation & Energy

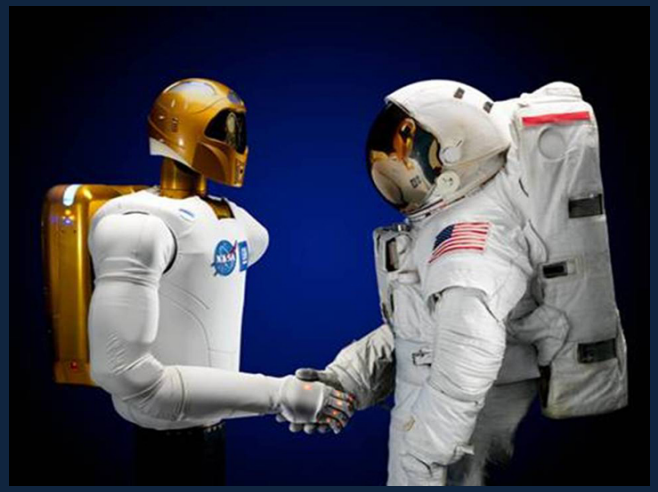
Personal and Homeland Security

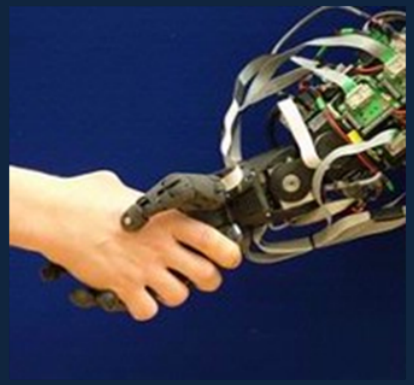
Space and Undersea Exploration

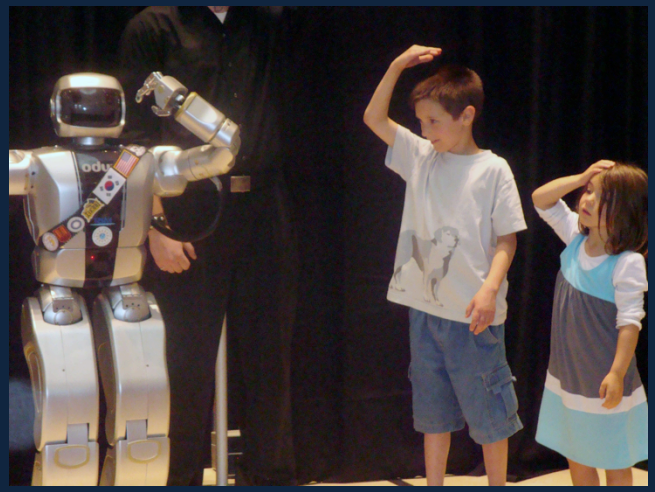
Education and Workforce Development

A new era of collaborative robots

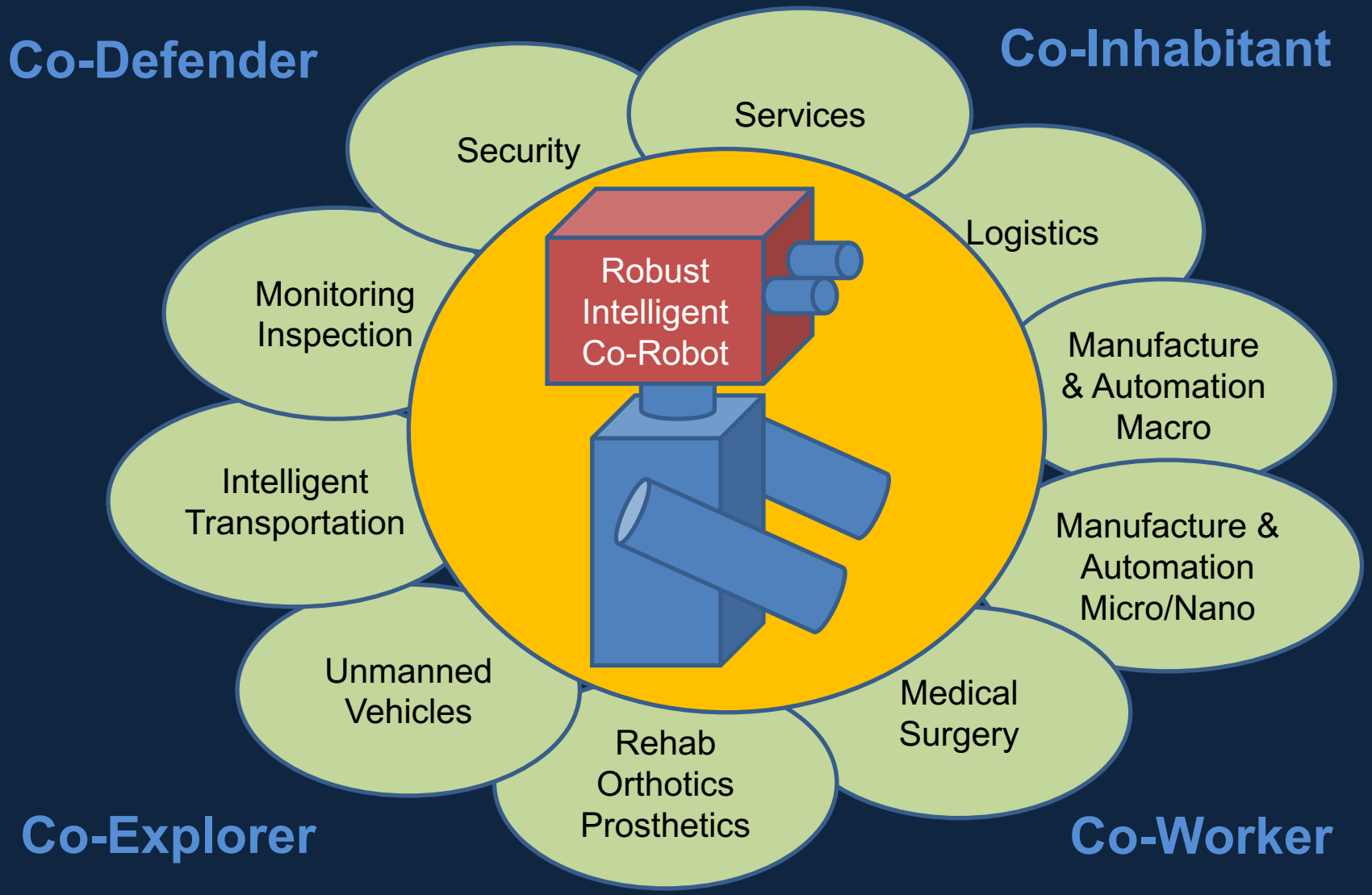
New machines that will work with humans as co-workers, co-protectors, co-drivers, co-explorers, and co-inhabitants, to enhance personal safety, health and productivity







Immense possibilities for co-robots



NRI Thrust Areas

Fundamental research in robotics science & engineering

Understanding the long term **social, behavioral, and economic implications** across all areas of human activity

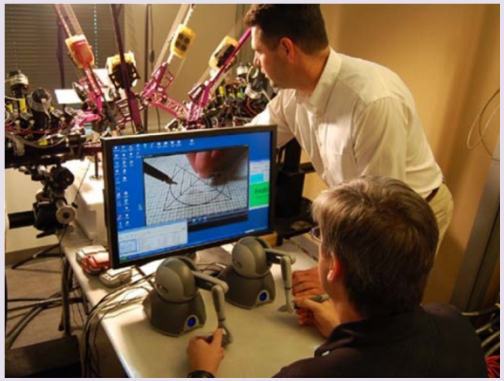
Use of robotics to facilitate and **motivate STEM learning** across the K-16 continuum

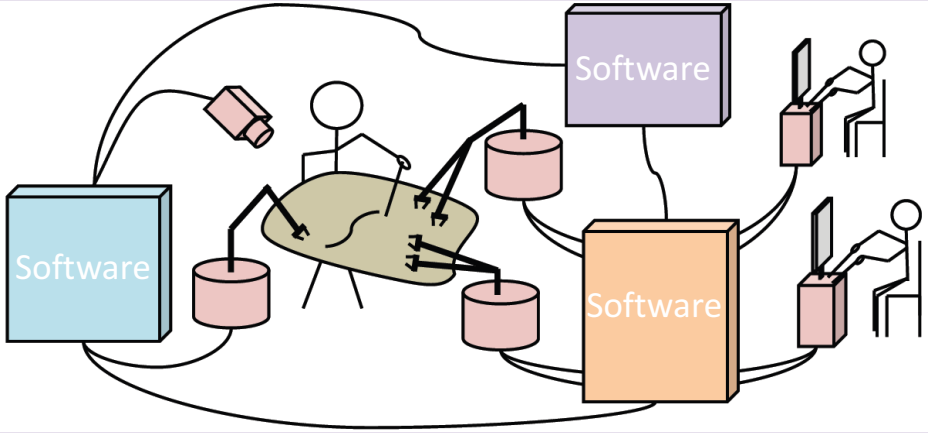
Fundamental Research into Co-Robotic Apprenticeship for Manufacturing and Surgery

Experts and Apprentices routinely collaborate - Why not robots?

Stanford, Berkeley, UC Santa Cruz, Johns Hopkins, U of Washington, Intuitive Surgical, Inc., Willow Garage, Inc., Spirit Aerosystems

This project advances the fundamental science of human-robot collaborative systems guided by specific applications from surgery and manufacturing. This work will enable robots and humans to learn from each other while working side-by-side and at a distance.



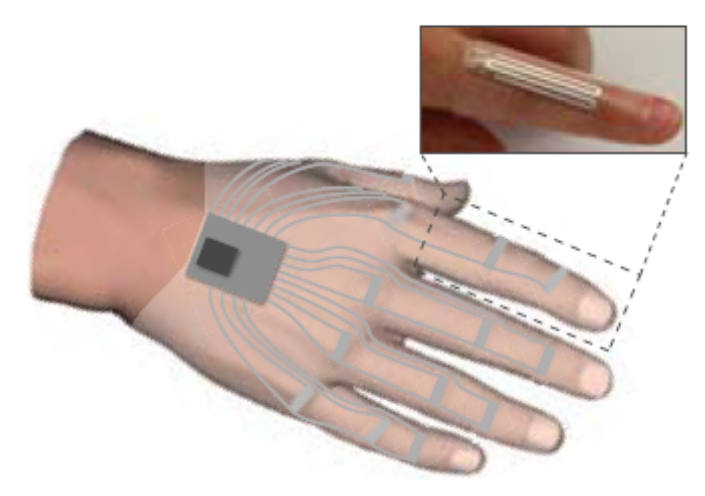


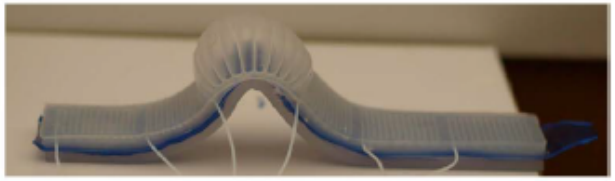
Fundamental Research into Safe, Soft Actuators for Co-Robots

Intrinsically safe human assistants

MIT, Harvard University, University of Colorado

Humans are soft and easily injured while robots have traditionally been hard, cold, and unyielding. To make co-robots intrinsically safe when working with humans, they must be soft and compliant like an elephant's trunk or a human's arm. New types of artificial muscles are required and new ways to control how they move must be explored. The result can be new types of soft, wearable "human-amplifiers," compliant hands, and safe robot arms.

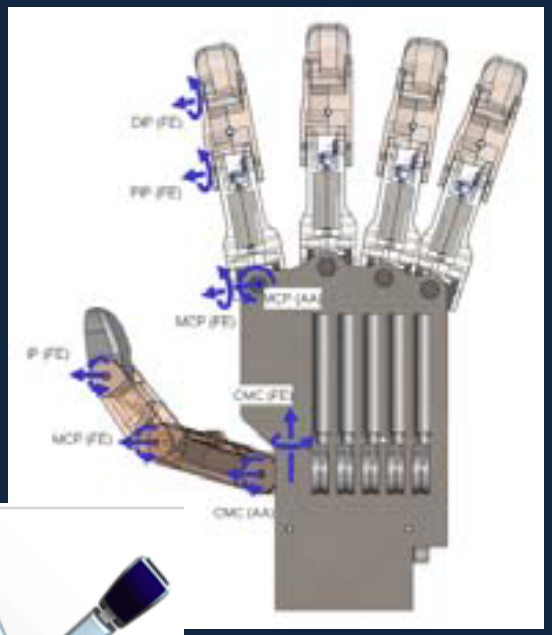




Fundamental Research into the Design of Co-Robotic Hands

Idaho State University, UC Irvine, National Instruments

The human hand is one of the most complex mechanisms in the biological world and is a testament to the intricacies of manipulation. Designing robotic hands and grippers for home tasks or factory tasks to grasp, lift, carry, and assemble various objects is difficult in the presence of uncertainty. This work investigates the design of grippers for research and manufacturing.

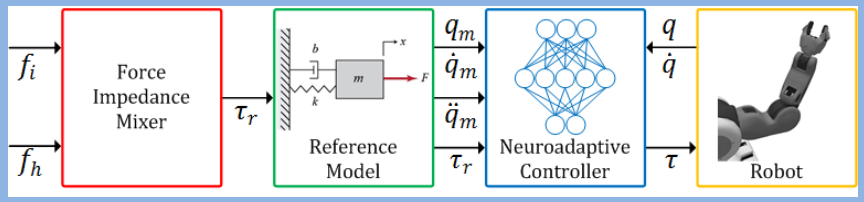


Multi-Modal Skin and Garments for Healthcare and Home Robots

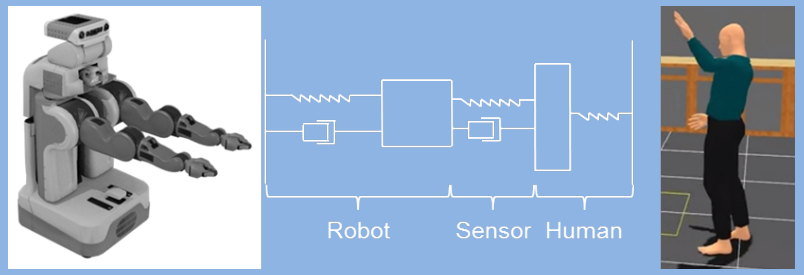
Univ. of Texas at Arlington, Univ. of North Texas Health Sciences,
Partners: Hanson Robotics, Advanced Arm Dynamics, National Instruments

In this project we create novel design and learning control tools for sensorized robot skin and clothes with applications in assisted living and upper limb prosthetics. We answer fundamental research questions related to:

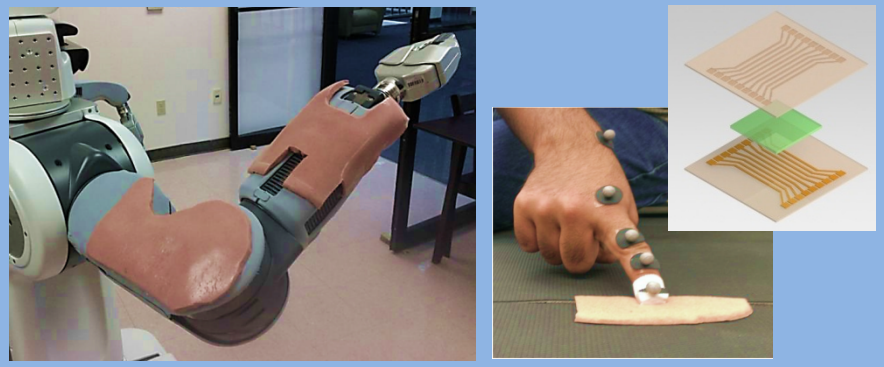
1. System Design: “where to place sensors on robot?”
2: Control and Learning: “both human and robot learn during interaction”
3: Devices: “distributed robot skin sensors embedded in flexible substrates”
4: Co-Robot performance: “how does this technology help humans?”



Neuroadaptive Impedance Control



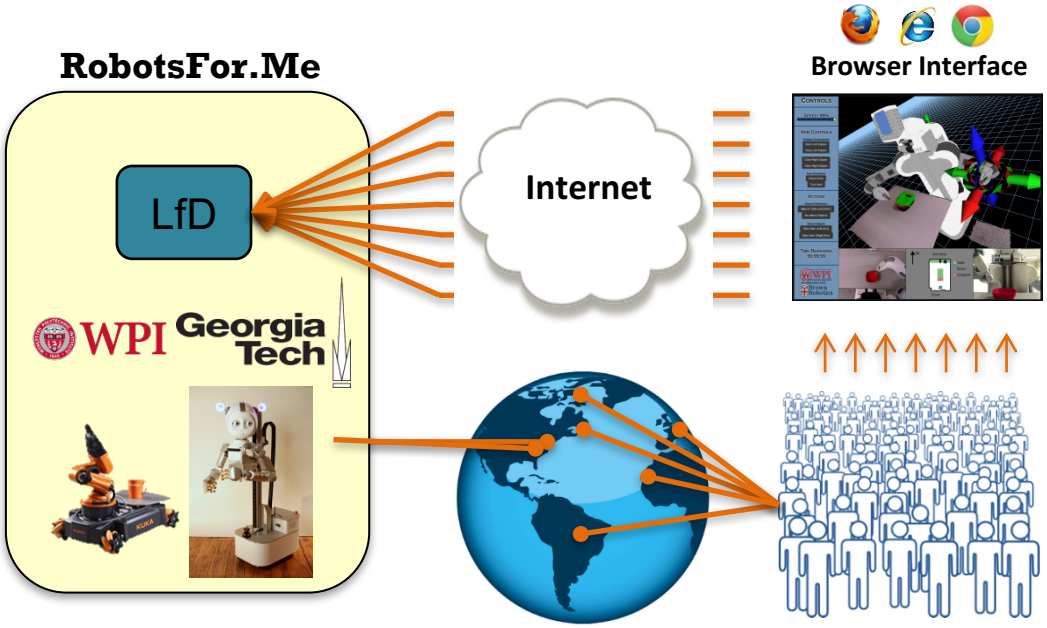
SkinSim – pHRI simulator

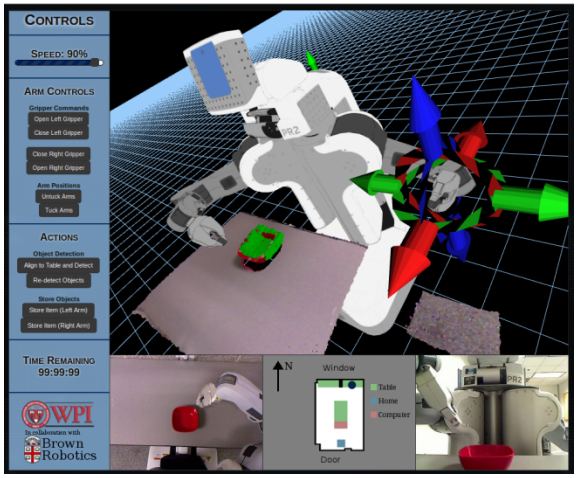


Learning from Demonstration for Cloud Robotics

Andrea Thomaz *Georgia Tech,* ***Sonia Chernova*** *Worcester Polytechnic Institute*

This work seeks to leverage cloud computing to enable robots to efficiently learn from remote human domain experts – Cloud LfD. Building on *RobotsFor.Me*, a remote robotics research lab, this research will unite Learning from Demonstration (LfD) and Cloud Robotics to enable anyone with Internet access to teach a robot household tasks. This research will result in policy learning and HRI research at an unprecedented scale, allowing for the collection of larger and more diverse volumes of data and leading to more general and robust task policies.





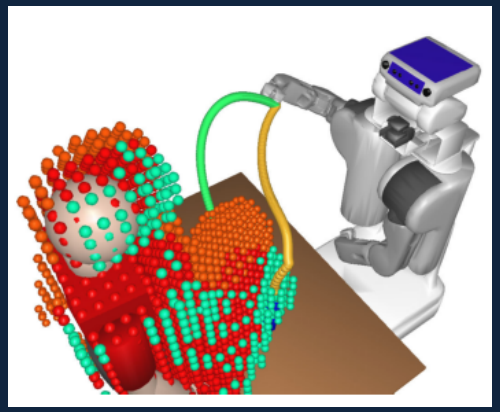
Human-Robot Collaboration for Manufacturing

Worcester Polytechnic Institute (WPI)
Massachusetts Institute of Technology (MIT)

This project advances the fundamental science of human-robot collaboration. This work will enable robots and humans to collaborate safely and efficiently in shared workspaces.

The methods developed in this project have the potential to significantly improve American competitiveness in manufacturing; especially for small-batch manufacturing and burst production.

Humans collaborating in manufacturing



The goal: Human-robot collaboration

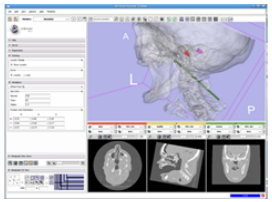
Managing Uncertainty in Human-Robot Cooperative Systems

Johns Hopkins University

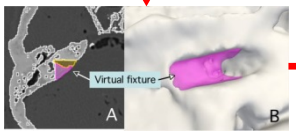
While robots are often used in highly-structured manufacturing tasks, it remains challenging to apply them to less structured tasks, such as surgery and machine servicing, due to the uncertainty arising in these tasks and environments. By combining human strengths in reasoning with machine capabilities in precise sensing and motion, we can overcome the uncertainty and achieve successful human-robot partnerships to perform complex tasks that were previously considered impractical or infeasible.

Robotic Assistant for Neurosurgery

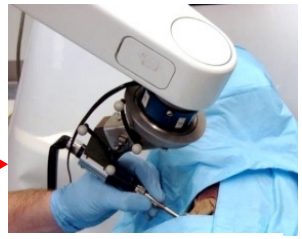
CT scan



Uncertainty in alignment (registration) between CT and patient



Safety boundaries



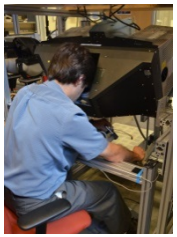
Robotic assistance

Telerobotic Satellite Servicing

remote (on-orbit) robot

Uncertainty due to time delay

ground-based test platform



master controller

Cooperative Underwater Robotic Networks for Discovery & Rescue

Chengyu Cao, Jun-Hong Cui, Kazem Kazerounian,
University of Connecticut

Goal: Develop fully autonomous and high performance underwater robotic networks for various missions

Autonomous Underwater Vehicle (AUV) networks are significant in ocean exploration

- Harsh environment in deep ocean motivates unmanned vehicles
- Benefits of vehicle networks: robustness, flexibility & coverage

Challenges

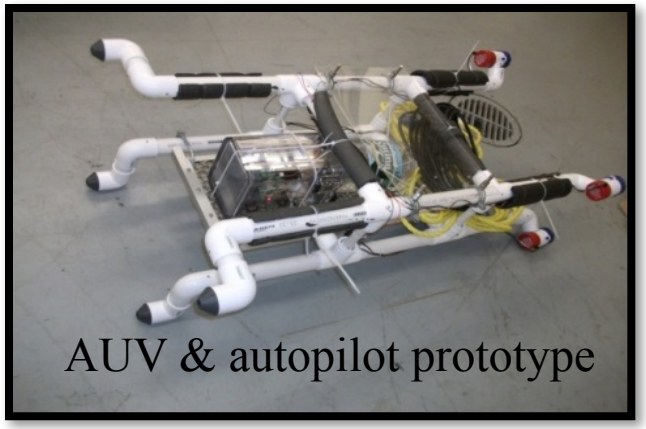
- Coordination of multi vehicles in uncertain environment
- Communication in harsh underwater environment
- High-efficient low cost platform design

Goals

- A novel cooperative control architecture
  - ✓ Local uncertainties
  - ✓ Other AUV's decisions
- An advanced underwater communication network
- An unique AUV design

Progress

- Design and simulate multi-agent cooperative control algorithms (flocking, formation flight, etc.).
- Design and implement acoustic underwater communication networks.
- Design and construct autopilot & vehicle platform.



AUV & autopilot prototype

Co-Robots for STEM Education in the 21st Century

University of California, Davis

This project studies how to use co-robot systems and math-oriented co-robotics competitions to enhance student engagement, increase student motivation in learning Algebra and subsequent STEM subjects, and interest in pursuing STEM related careers and post-secondary.

Introducing computing and robotics into the Algebra curriculum helps make abstract ideas concrete and allows students to apply mathematical concepts to real world problems.

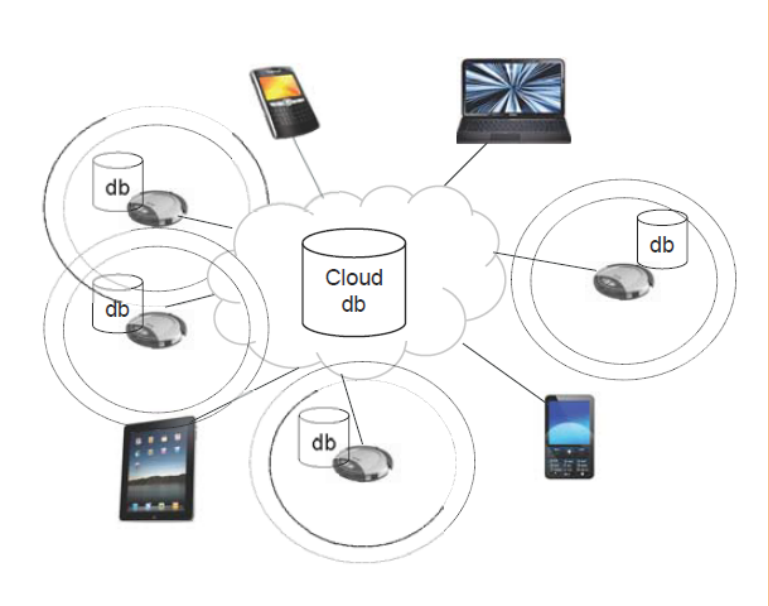
RoboPlay Competition is designed for K-12 students to play with robots while having fun and exploring their creativity in writing, art, music, choreography, design, video editing, and film production while at the same time seamlessly learning STEM subjects.

Innovative Teaching and Learning with Co-Robots for Undergraduates

Using Co-Robots to Teach Complex Concepts in the Computer Science Curriculum

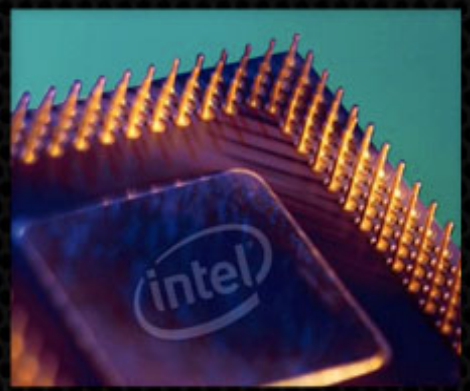
Rochester Institute of Technology

Robots are already being used to teach programming concepts to K-12 students and entry-level undergraduates. This project attempts to leverage the intrinsic interest in co-robots to teach more complex concepts to advanced undergraduates. Topics of interest include cloud computing, data mining, mobile-app programming.

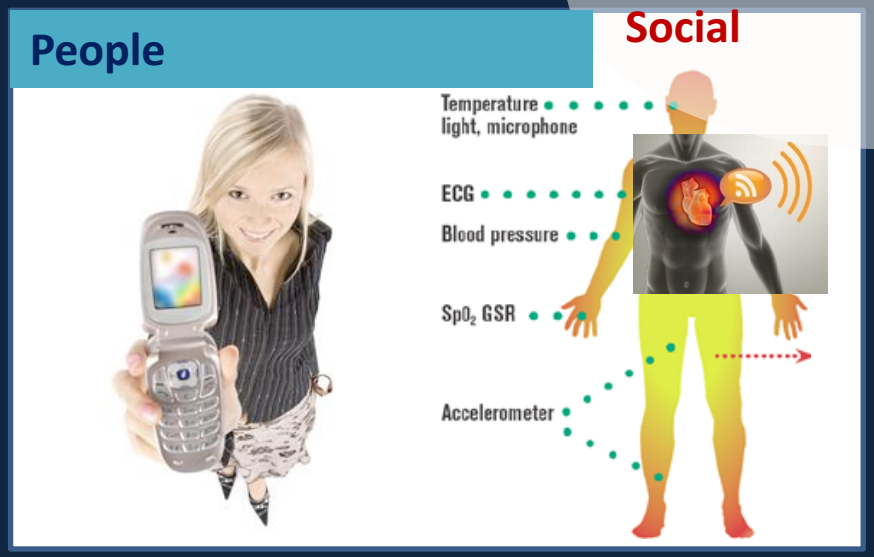


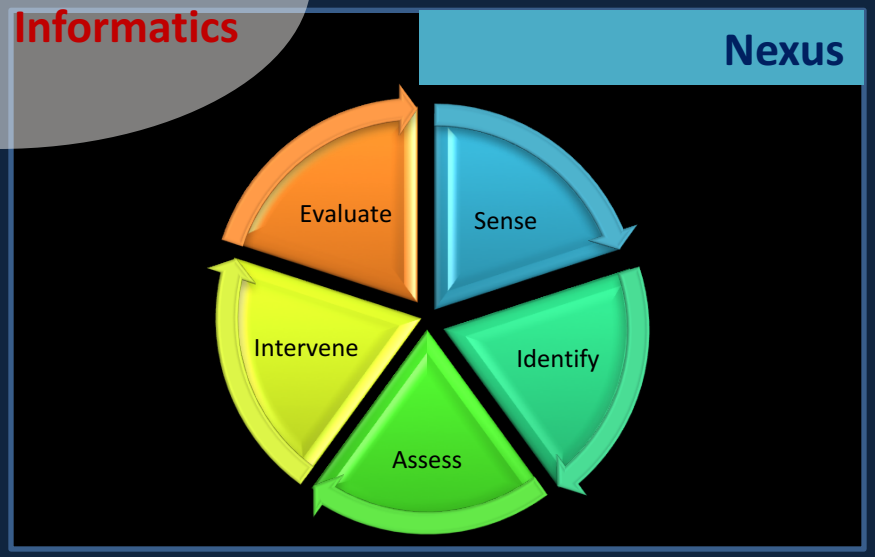
Ubiquitous deployment of sensors

The melding of the cyber and physical worlds enables smart systems all around us.



Sensors Everywhere are Enabling a Smart World

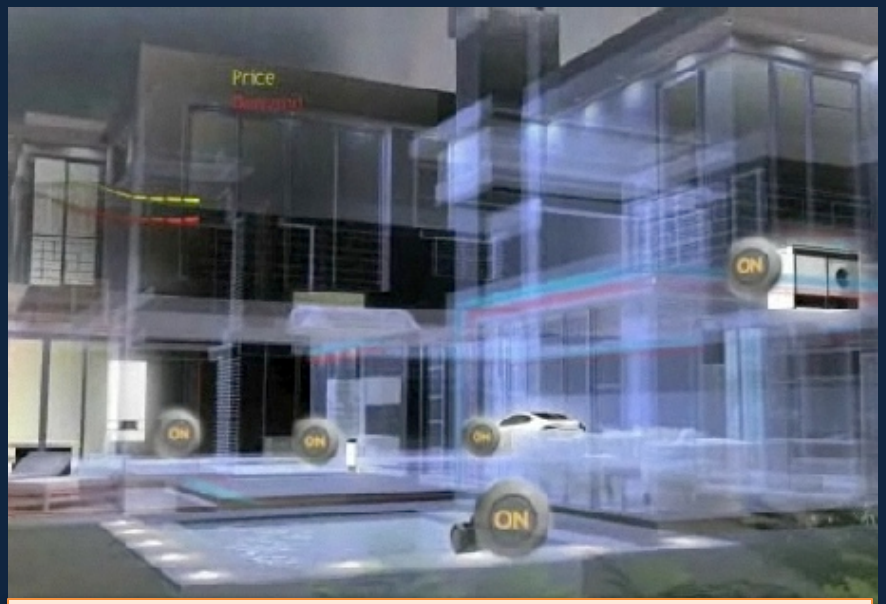




NSF is Enabling Smart Systems

National Robotics Initiative (NRI)

- ***Developing the next generation of collaborative robots, or co-robots, that work beside and cooperatively with people***
- Cross-agency collaboration: NSF, NASA, USDA, NIH, & DARPA



Cyber-Physical Systems (CPS)

- ***Deeply integrating computation, communication, and control into physical systems***
- Cross-agency collaboration: NSF, DHS, and DoT

Smart systems have the potential to transform multiple sectors

Advanced Manufacturing

Transportation

Critical Infrastructure

Health and Medical Care

Research to Enable Smart Systems


Image Credit: *MicroStrain, Inc.*

Cyber-Physical Systems (CPS)

- ***Deeply integrate computation, communication, and control into physical systems***
- Aspects of CPS include pervasive computation, sensing and control; networking at multi- and extreme scales; dynamically reorganizing/reconfiguring systems; and high degrees of automation
- Dependable operation with high assurance of reliability, safety, security, and usability

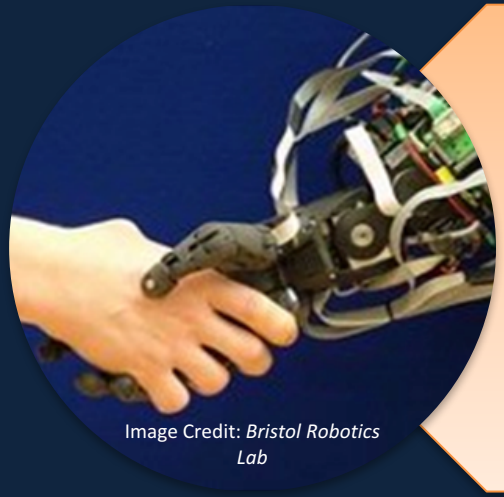


Image Credit: *Bristol Robotics Lab*

National Robotics Initiative (NRI)

- ***Develop the next generation of collaborative robots, or co-robots, that work beside and cooperatively with people***
- A nationally concerted cross-agency effort among NSF, NASA, USDA, and NIH
- Initiative includes aim to understand the long-term social, behavioral, and economic implications
- Potential to enhance personal safety, health, and productivity

Research to Enable Smart Systems


Image Credit: *MicroStrain, Inc.*

Cyber-Physical Systems (CPS)

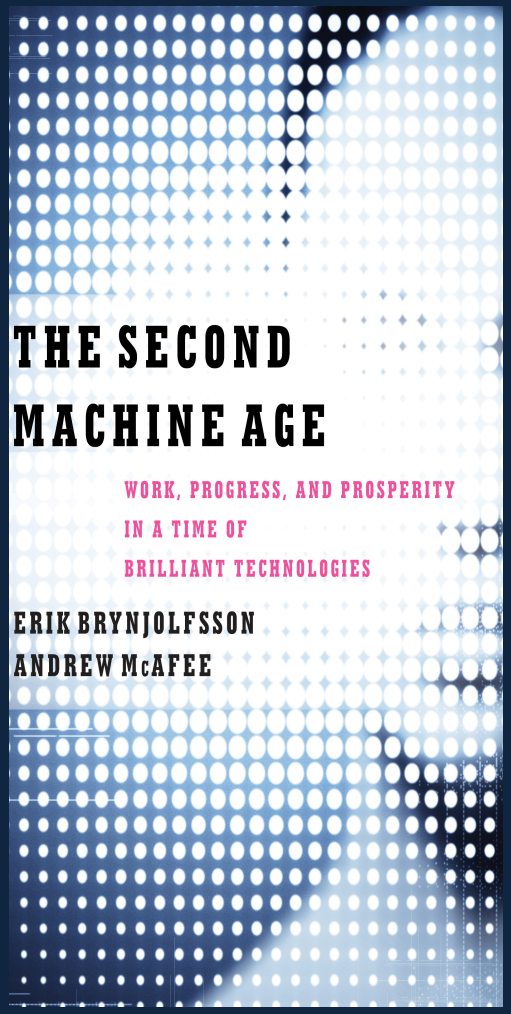
- **Since launch in 2008:**
  - $250M+ NSF total investment
  - 250+ awards


Image Credit: *Bristol Robotics Lab*

National Robotics Initiative (NRI)

- **Since launch in FY2012:**
  - $110M+ interagency total investment
  - $60M+ NSF total investment
  - 120+ awards

The Second Machine Age



"In short, we're at an inflection point—a point where the curve starts to bend a lot—because of computers. We are entering a second machine age."

Image courtesy Erik Brynjolfsson and Andrew McAfee

THE FUTURE OF EMPLOYMENT: HOW SUSCEPTIBLE ARE JOBS TO COMPUTERISATION?

Osborne and Frey, 2013, Oxford University

"According to our estimates, about 47 percent of total US employment is at risk."

"Our model predicts that most workers in transportation and logistics occupations, together with the bulk of office and administrative support workers, and labour in production occupations, are at risk."

Questions? Ideas? Thoughts?

pkhargon@nsf.gov