Nuclear & Applied Robotics Group

INTERDISCIPLINARY RESEARCH PROGRAM FOR APPLIED ROBOTICS IN HAZARDOUS ENVIRONMENTS

Interdisciplinary Graduate Program for Automation in Nuclear Applications

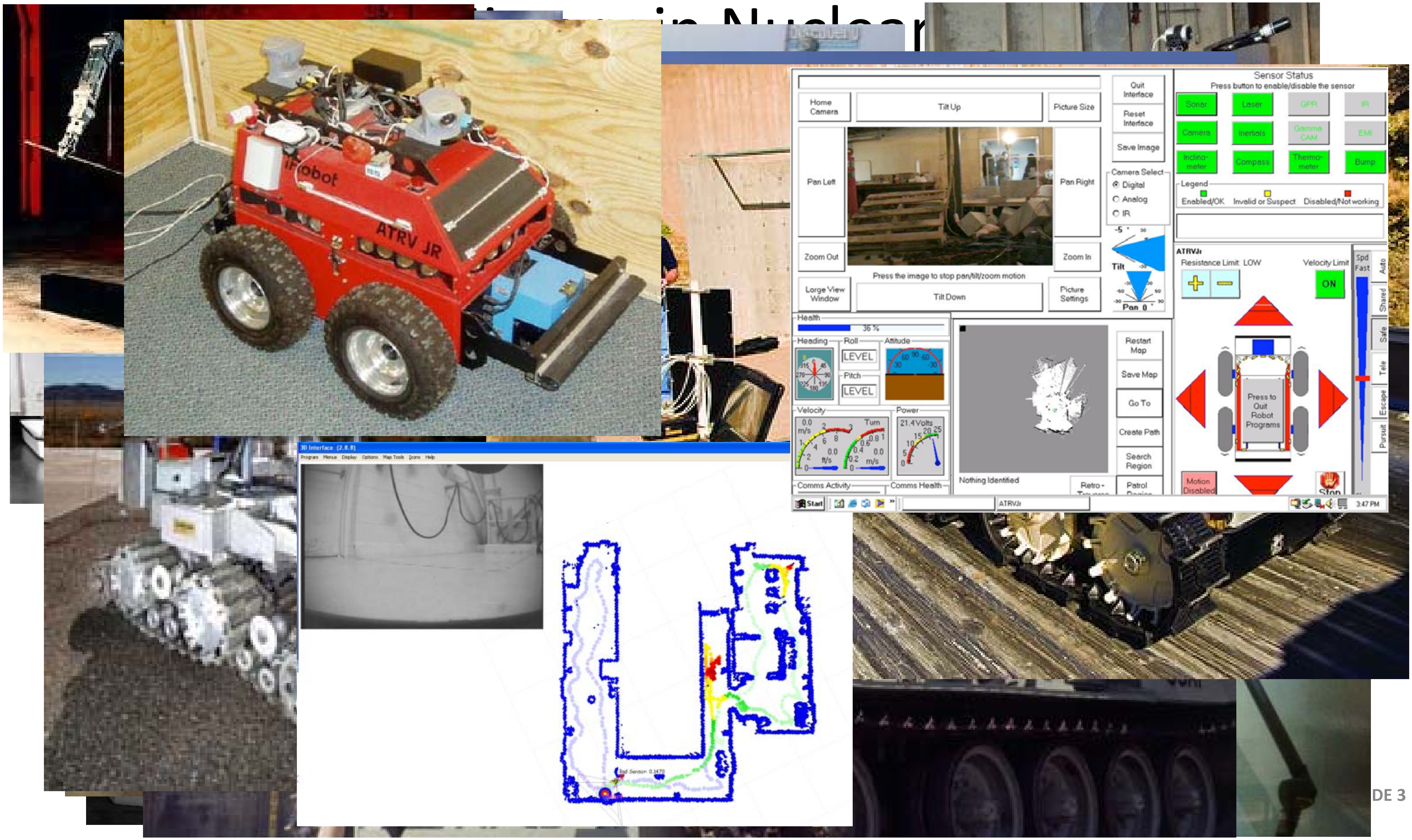
Mitch Pryor, U.T. Austin

http://robotics.me.utexas.edu

A bit of background…

…which motivated a research philosophy…

…and some positive results.


in Nuclear
iRobot
ATRV JR
Sensor Status
Press button to enable/disable the sensor
Sonar
Laser
GPR
IR
Camera
Inertials
Gamma CAM
EMI
Inclino-meter
Compass
Thermo-meter
Bump
Legend
Enabled/OK
Invalid or Suspect
Disabled/Not working
Quit Interface
Reset Interface
Save Image
Home Camera
Tilt Up
Picture Size
Pan Left
Pan Right
Camera Select
Digital
Analog
IR
Zoom Out
Zoom In
Press the image to stop pan/tilt/zoom motion
Large View Window
Tilt Down
Picture Settings
Tilt
Pan
Health
36 %
Heading
Roll
Attitude
LEVEL
Pitch
LEVEL
Velocity
Turn
Power
21.4 Volts
Restart Map
Save Map
Go To
Create Path
Search Region
Patrol
Nothing Identified
Comms Activity
Comms Health
ATRVJr
Resistance Limit LOW
Velocity Limit
ON
Spd
Fast
Auto
Shared
Safe
Tele
Escape
Pursuit
Press to Quit Robot Programs
Motion Disabled
Stop
Start
3:47 PM
3D Interface (2.0.0)

In Summary…

- Above is a **small** portion of robotics for nuclear environments
  - Other hazardous environments (space, mining, bio, ocean, military, drilling, surgery, and being played with by kids).
  - So…. lot's of great work… often done in silos.
  - DOE EM knowledge base hosted by FIU (doeresearch.fiu.edu)
- The **vast** majority of solutions are either pure tele-operated or fixed automation.
- Key Feedback after Fukushima robotic deployment. The critical lacking elements from the project were (Nagatani, 2013):
  - Field knowledge for researchers
  - Precise communication between researchers and users
  - Education and training of users

A typical University to Lab Presentation…

"Robots are awesome!"

"There are some great projects where we could use this stuff!!"

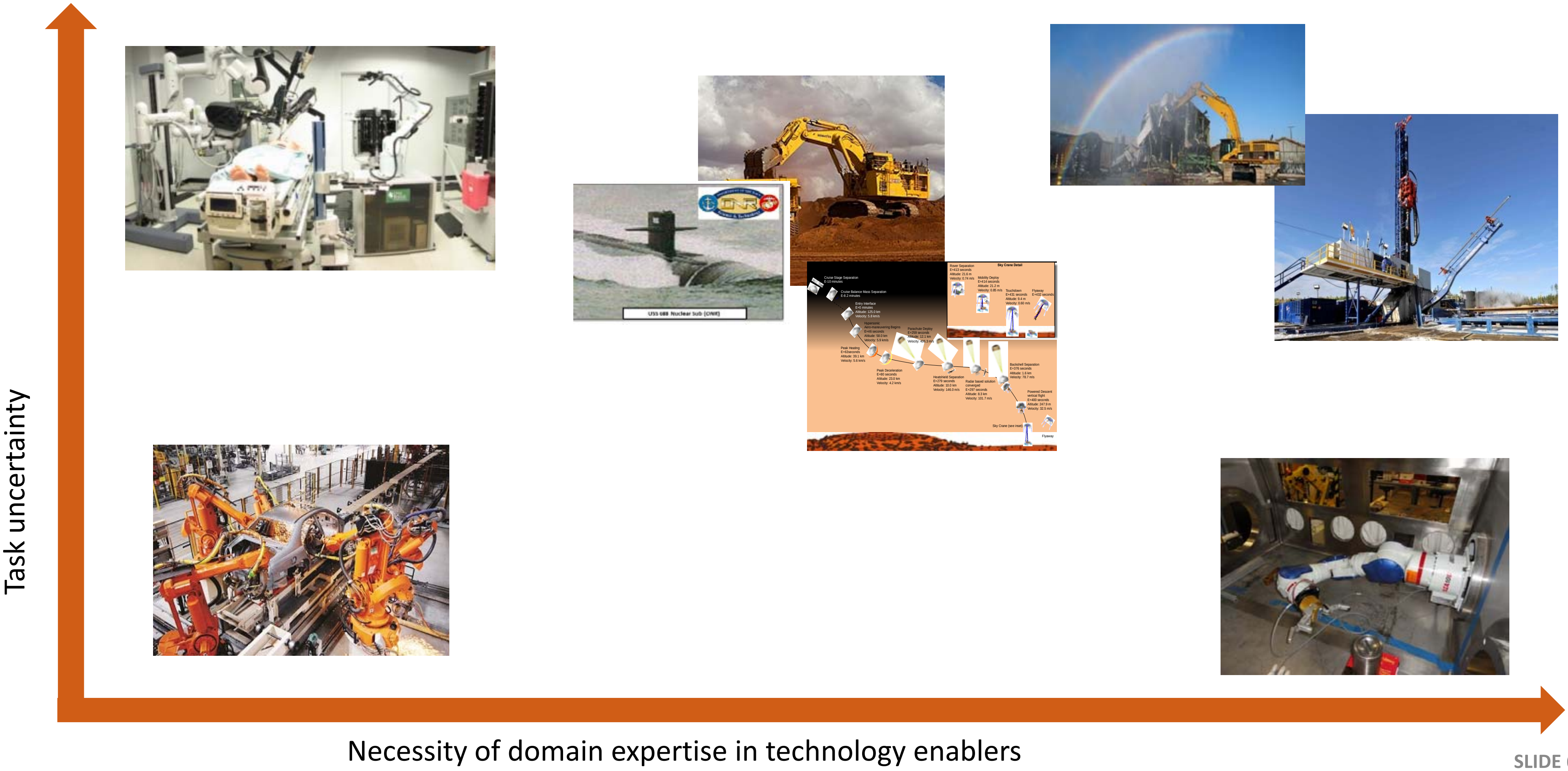
"Here's a really long list…"

"Anyway, thanks for coming…."

The issues…

- A **bi-directional knowledge gap**
  - Lack of an adequate workforce to transfer automation technology to the labs.
  - Failure to understand the demanding requirements for deploying systems in nuclear domains.
- Universities demonstrate **technologies not solutions**.
- Lack of **mission relevant** demonstrations.

Acknowledge we are working on a hard problem…



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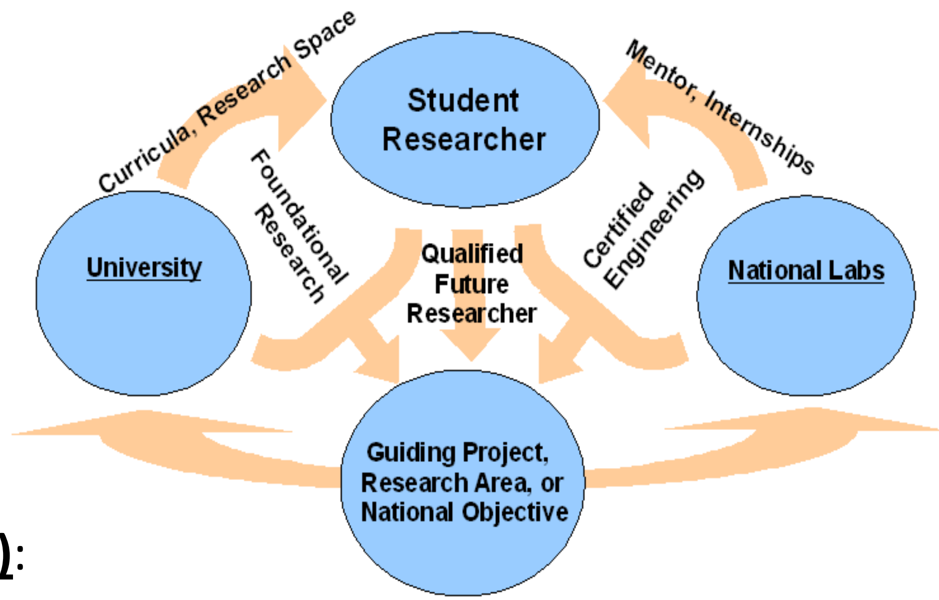
The Nuclear Robotics Group

<u>Program Objective</u>: *Train the **next generation of engineer researchers** to deploy **advanced, flexible automation** across the national-industrial nuclear complex.*

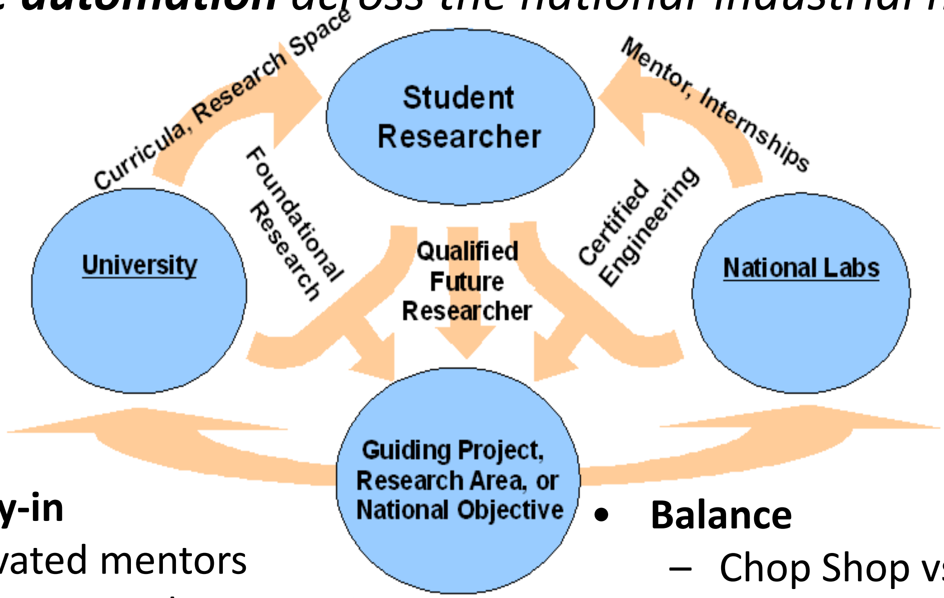


<u>Success metric(s)</u>:

- Reduce operator dosage and improve operational safety *without* a loss in operational efficiency.
- Number of students joining the DOE workforce with training in both nuclear and automation domains

Key Challenges

<u>Program Objective</u>: *Train the **next generation of engineer researchers** to deploy **advanced, flexible automation** across the national-industrial nuclear complex.*



- **DOE Complex Buy-in**
  - Identify motivated mentors
  - Identify challenging, relevant projects
- **Critical Research Challenges**
  - Human/machine interactions
  - Task completion with uncertainty
  - Safety, safety, safety…
- **Balance**
  - Chop Shop vs. Pie-in-the-sky
  - Mechanical vs. Nuclear emphasis
- **Workforce Development**
  - Identify outstanding candidates with diverse backgrounds
  - Generate candid feedback

Program Curricula, Masters

Prerequisite Courses (pick at least 1 of the 3)
C++ Data Structures and Algorithms (undergraduate)
Modern Physics for Engineers (undergraduate)
Matrices and Matrix Calculations (undergraduate)

Mandatory Courses
Introduction to Nuclear Engineering (undergraduate)
Radiation Shielding (graduate)
Health Physics / Radioactive Waste Management (graduate)
Math Methods in Nuclear Engineering (graduate)
Reactor Theory (graduate)

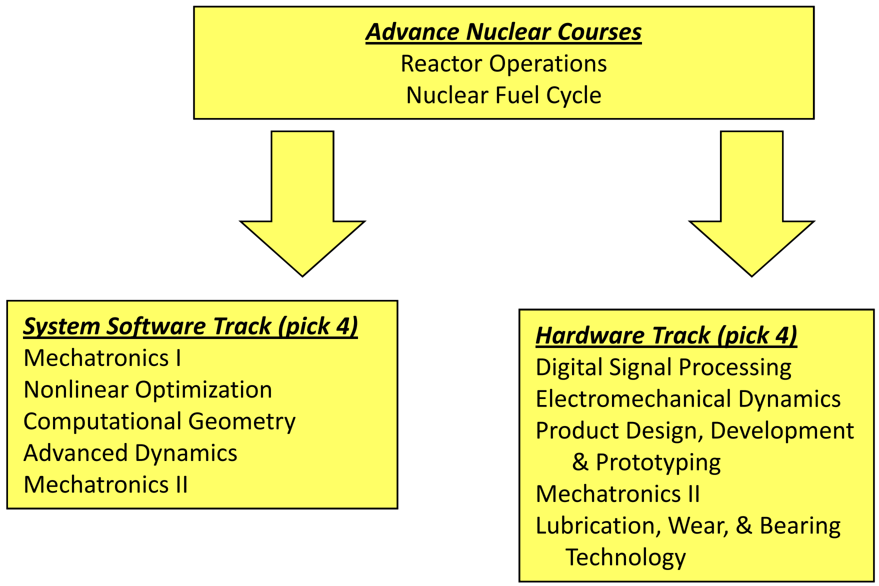
System Software Track
Robot Geometries (graduate)
Advanced Robot Dynamics (graduate)

Hardware Track
Design of Complex Systems (graduate)
Robotics and Automation (graduate)

Emphasis is on

- Nuclear science and safety
- Robot design, modeling and control
- Fundamentals of design (Hardware Track) or programming (Software Track)
- **Students work as interns at a national lab during the summers**

Program Curricula, PhD



Emphasis is on

- Automation within a nuclear science context.
- Curricula focused on specialization which is, in large part, determined by supporting project.
- PhD Curricula is highly customizable.
- **ABD students often work as full-time affiliates at a National Lab**

Research Philosophy

- **Applied Research:** As in **apply** cutting edge research to develop application solutions.
- Define/quantify desired autonomous capabilities
  - Evolutionary not revolutionary **(build trust!)**
  - Reduce the burden on the operator
- Safety, safety, safety.
  - Proven Hardware
  - Minimize the risk **(build trust!)**
  - Comprehensive safety architecture
- Address Human Factors
  - Simplify the interface **(build trust!)**
  - Minimize context switching
- Hardware agnostic operating system and communication protocols **(build trust!)**
- Relevant field testing
  - Line managers need to see their application in our demonstration **(build trust!)**
- Develop domain experts, not advocates for a specific technology.
  - Find the right solution **(build trust!)**
- **Build Trust!**

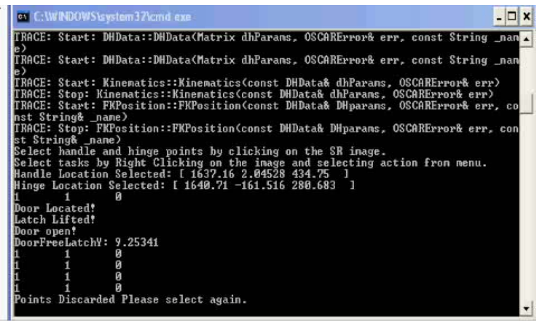
Autonomy levels for manipulation

Level	Tele-op (Level 0) → Autonomy…
1	Eliminate operator’s need to manage the robot’s internal configuration.
2	Eliminate the operator’s responsibility for avoiding undesired contact with the environment.
3	Eliminate the operator’s responsibility for moving the robot to locations of interest.
4	Eliminate the operator’s responsibility for selecting grasping configurations for retrieving objects.
5	The operator directs the system to complete tasks with autonomously completed subtasks (such as pick & place).
6	Eliminate the operator’s responsibility to avoid threshold forces for contact tasks such as opening a door or exceeding the system’s payload.
7	Eliminate the need for detail necessary to communicate a task (or subtasks) to the system.
8	Integrate capability to complete tasks that require precision and/or control a specific force profile
9	Eliminate the need for an operator in the loop for tasks triggered by independent external events (i.e. timer on oven, low battery notification, arrival of material, etc.)
10	Based on prior tasks, the system anticipates future tasks to be completed.

Visual and Audio Feedback
Master/Joystick
tele-operation
(Hokayem and Spong)
Color Key
Resource management
Environmental Awareness
Operator Interface
Motion & Task Planning
Peripheral & Sensor Integration
Perception
Range checking
Safe-stop motion capability
Env. collision detection (sensed)
Redundant optimization
Anomalous joint torque detection
Actuator torque measurement
Env. collision detection (model)
EEF force data
Haptic notification
Sensor-based contact identification
Self-collision detection (model)
Generate 3D environmental data
Proximity sensing
Model-based obstacle avoidance
0
1
2
Map point & clik to vision data
Compliant grasping
Future performance requirements
Detect large EEF forces
Object surface characterization
Contact-based model development
Trajectory generation
Sensor-based target acquisition
Task queuing
Real-time model generation
Object geometric characterization
Haptic feedback
Payload and inertial force awareness
Workspace awareness
Trajectory generation w/ sensor data
Select grasp compatible with entire task set
State machine
Model-based target acquisition
Tactile feedback
High bandwidth sensing
Multi-sensor models
3
4
5
6
Object recognition
Notification
Tolerate occluded objects
Voice commanded UI
Sensor verification of task completion
To be determined…
System resource monitor
Reactive trajectory regeneration to external events
Sensors to monitor external events
System state supervision
System performance awareness
Archiving for learning, etc.
7
8
9
10
towards autonomy

Example: Reduce operator’s burden

Objective: Open a cabinet with a right click.

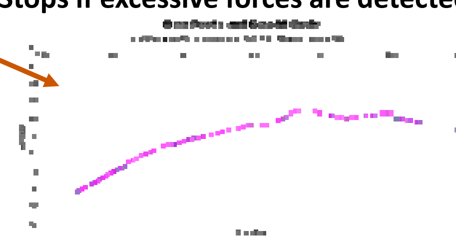


- •**Operator** identifies latch
- •**Vision:** determine distance to door
- •**Force:** safe contact with door

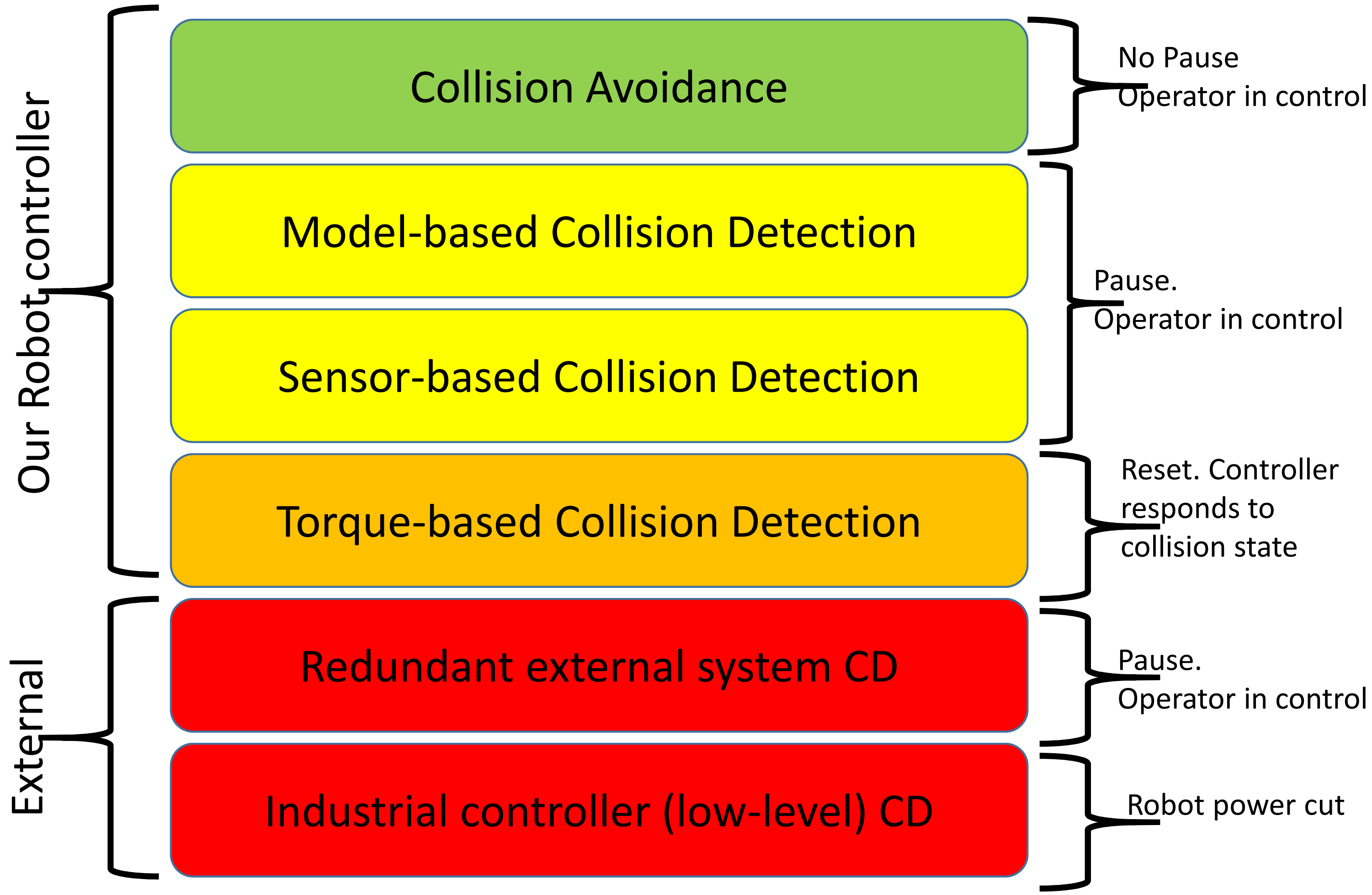
- •**Vision**: Approximate latch height
- •**Force: maintain contact with door**
- •**Force: lift latch and confirm location**

- •**Lateral forces** (red) **minimized**
- •**Latch-lifting force** (blue) **maintained**
- •Force data used to estimate door parameters

- •Door radius and hinge center estimated
- •**Stops if excessive forces are detected**



Safety, Safety, Safety…



Safety architecture implementation, examples

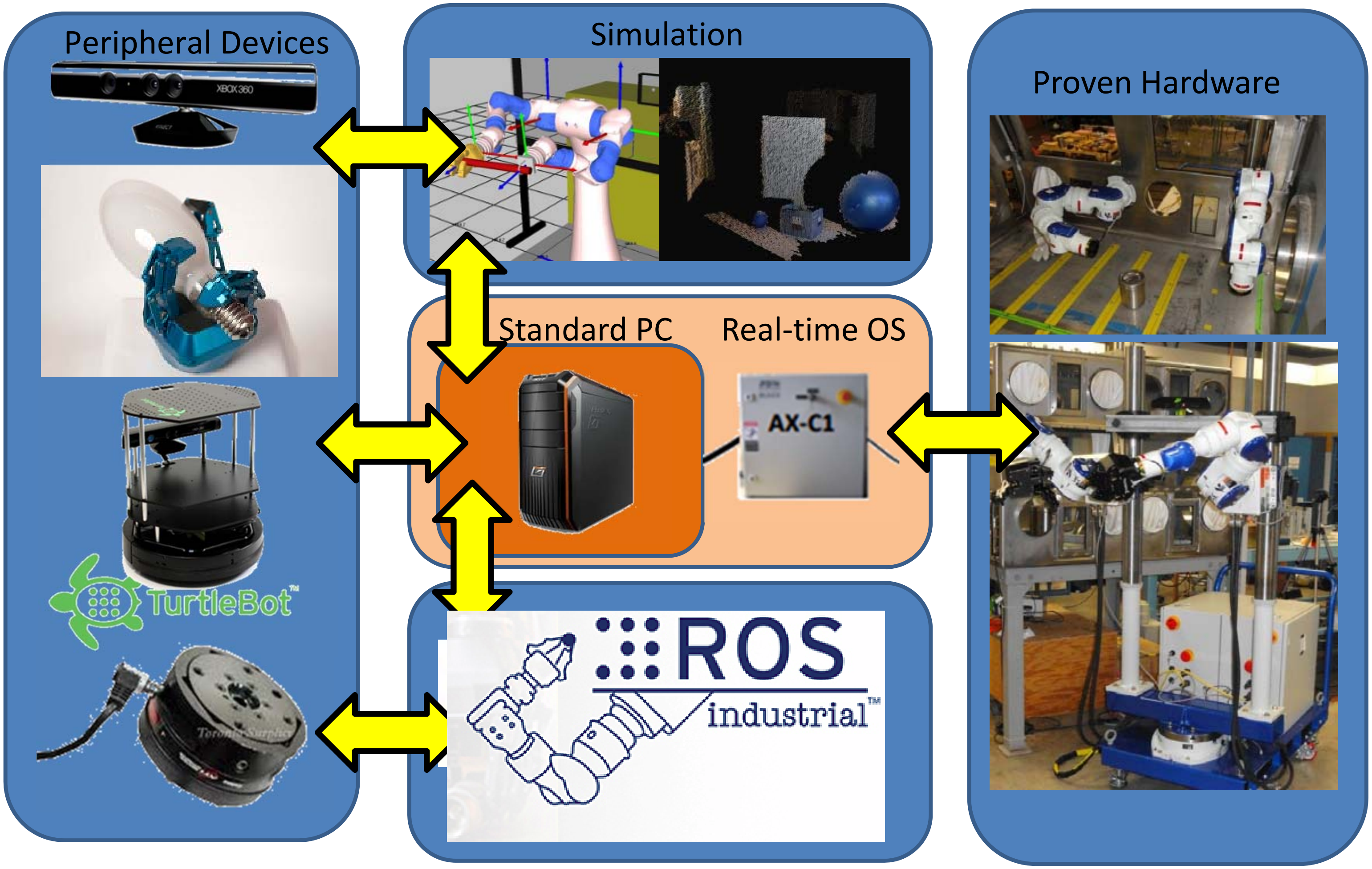
Torque-based CD

- **Mapped motor currents to torques**
  - Industrial manipulators
  - Black-box model
- **Modeled compression/force imparted to body**
  - BGIA data used to simulate human collisions
  - Validated experimentally

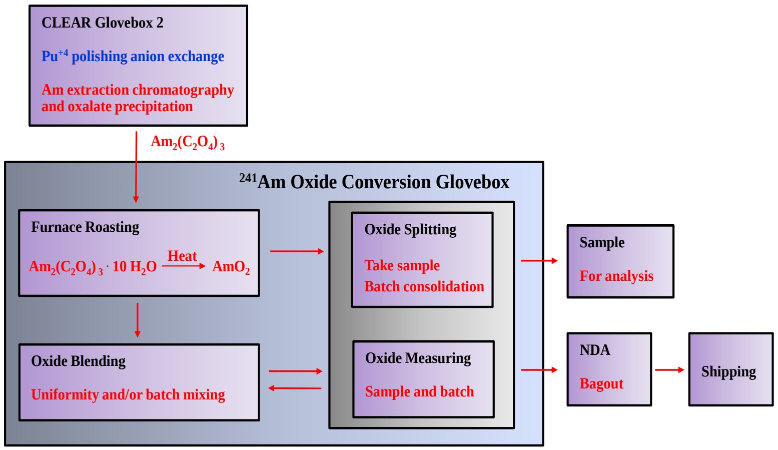
Redundant external CD

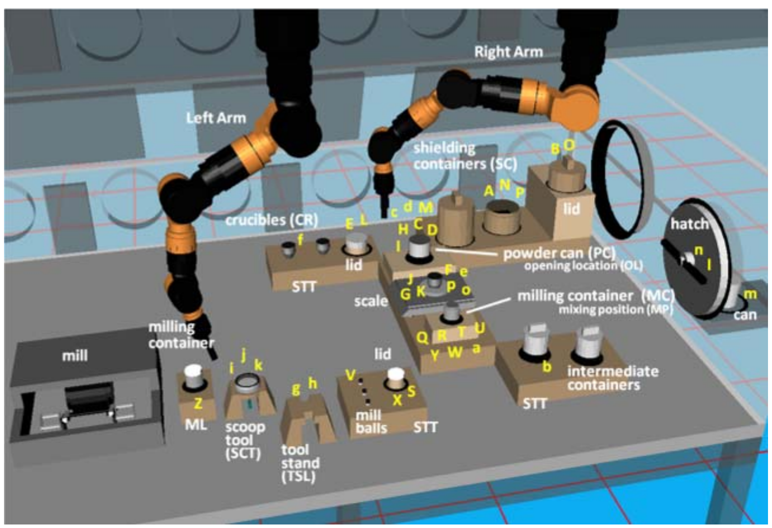
Smart sleeve concept
(Thompson, 2012)

Hardware agnostic operating system



Interdisciplinary / Objective Research





- **Large-scale Am-241 Recovery**
  - Purify americium oxalate ($Am_2(C_2O_4)_3$)
- **Objective:** Reduce extremity and whole body dose
  - Time, distance, shielding
  - Fewer material transfers
  - Reduce manual processes

  Any & All Opportunities
- **Efforts**
  - Evaluated process components.
  - Developed remote handling requirements
- **Conclusions:** Robotics are feasible but may not be necessary. Large dose reductions are possible via:
  - process optimization
  - improved powder handling methods
  - shrewd shielding solutions
  - automation

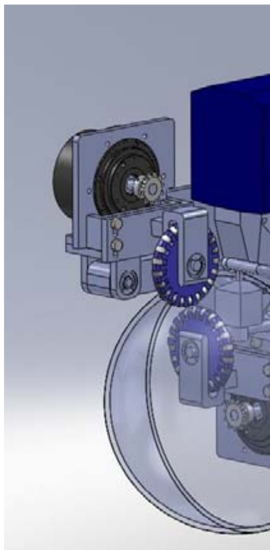
Engineering vs. Research

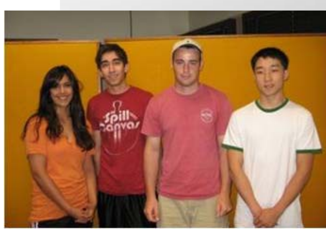
- **A problem needs a solution, BUT…**
  - May be more engineering than research
  - Want something quickly
  - Want fresh eyes on the problem
    - Unbiased by current practice.
- Want to generate a lot of new ideas
- Simple as possible but NOT simpler.
- Pulling graduate researcher from topic to topic is not ideal.

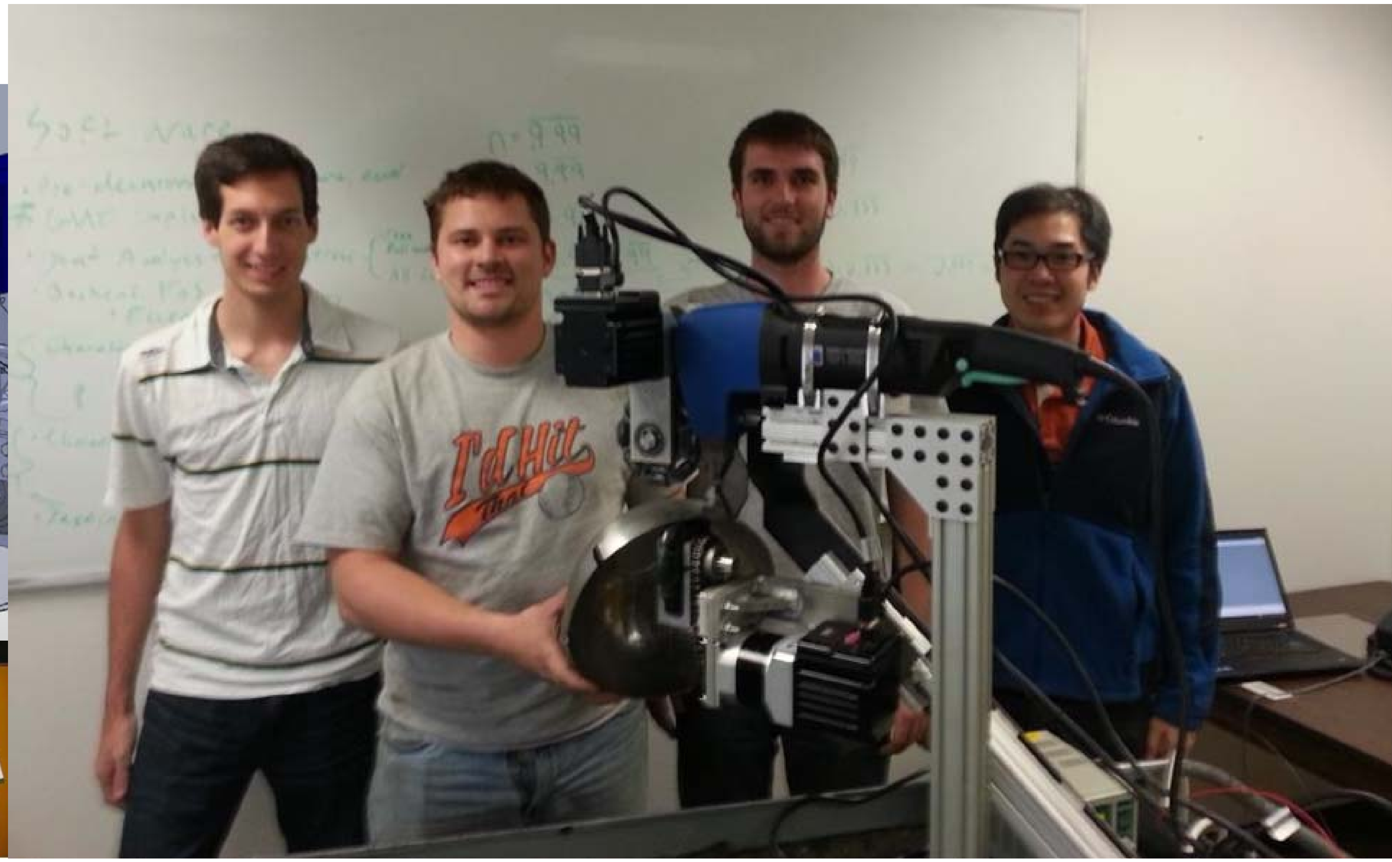
- **Let me give you an example…**



Research in Engineering!







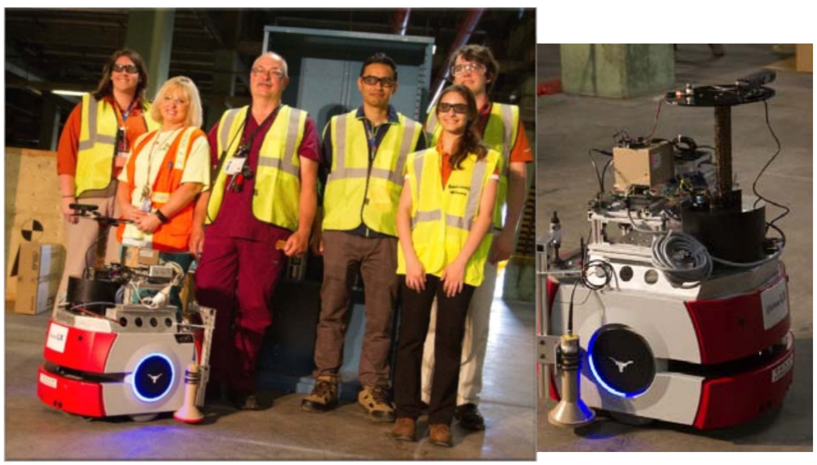
Which built trust…

- **Material reduction application**
  - Path plans automatically generated from geometric properties.
  - ROS/Labview integration for controlling pneumatic gripper
  - F/T sensor detects/prevents binding events and object warping
  - Permits operator override to remotely jog/tele-operate system
  - Vision system allows parts to be picked up without fixturing.
  - **Safe, yet flexible solution!**

A bit of background…
…which motivated a research philosophy…
…and produced some interesting stuff.

Application Areas

Material Reduction



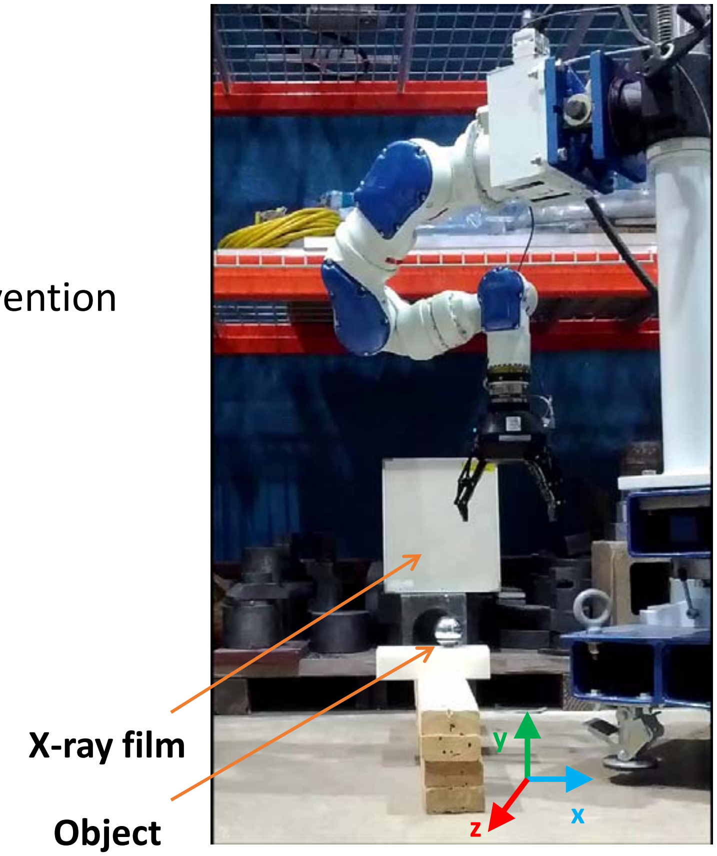
Remote Survey and Inspection

Glovebox manufacturing

Automated Non-Destructive Testing (NDT)

Non-Destructive Testing

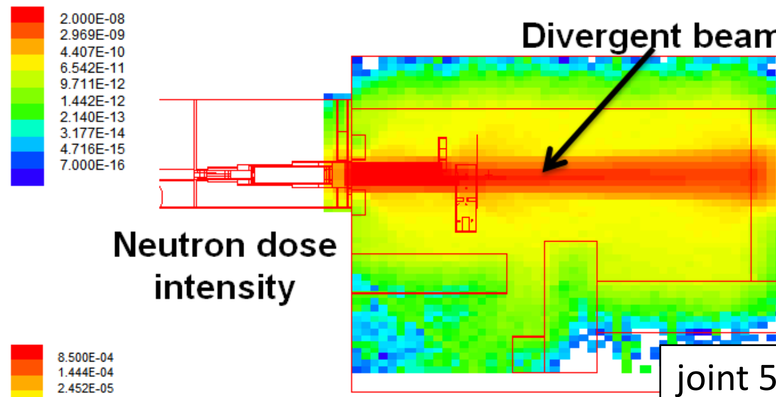
- Robotic motion control system
  - Digital radiography, computed tomography
  - helical scans for large objects. (see video)
- Advantages:
  - Reduced exposure (ALARA)
  - Autonomously image multiple samples without worker intervention
  - Increased sample throughput
  - Better process control (autonomously align weld seams)
  - Orientation of sample in 3D space

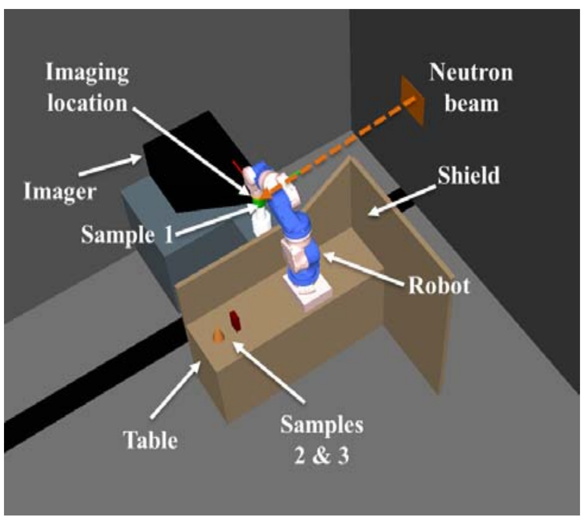


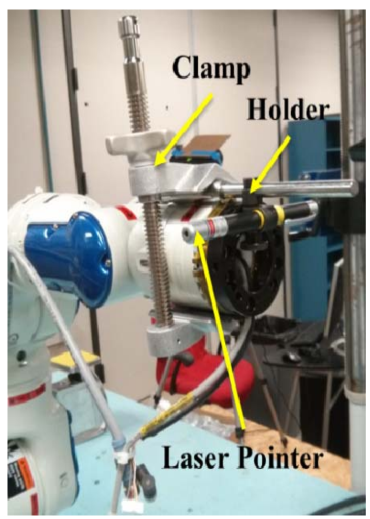
Robot in NETL’s Neutron beam port: http://youtu.be/-37F8Tq3rTE

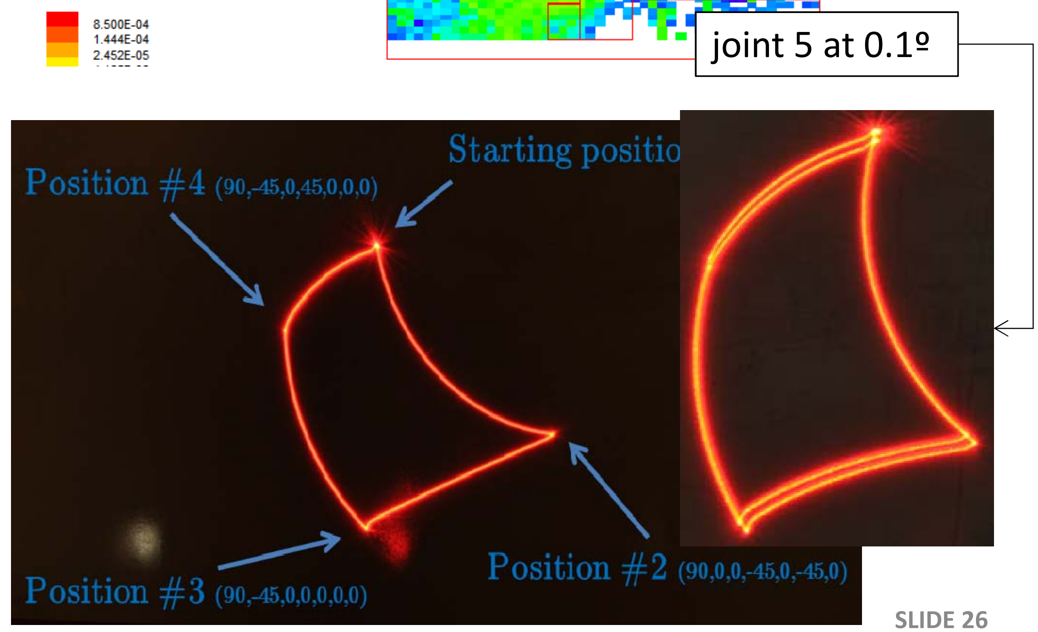
Validating NDT Automation

- Demonstrate feasibility
  - metrology
  - survivability (MCNP)
- Quantify trade-off between field effects and precision
- Optimize configuration (design)
- Demonstrate solution



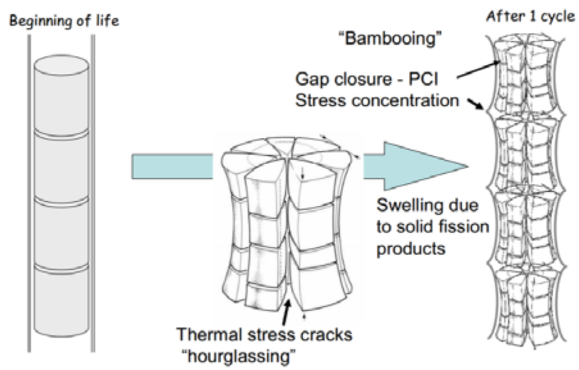


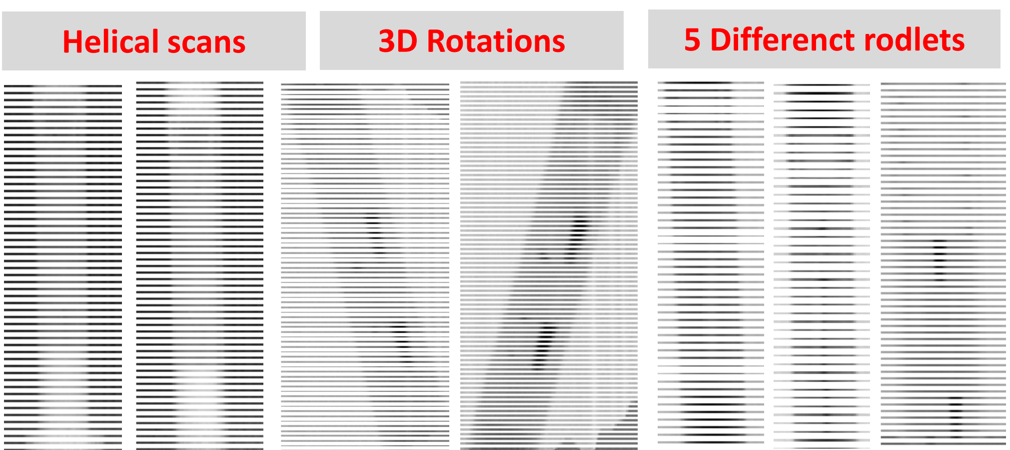




Demonstrating NDT Application

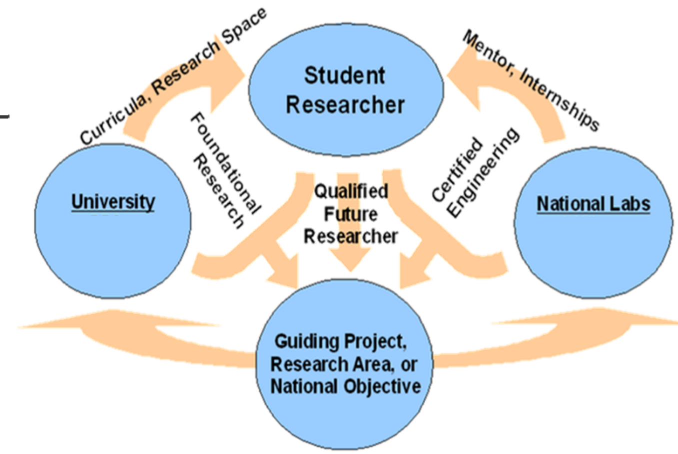
- Development of irradiation and burn-up damage in fuel rod
  - ~20,000 rad/hr = dose rate from activated fuel rods





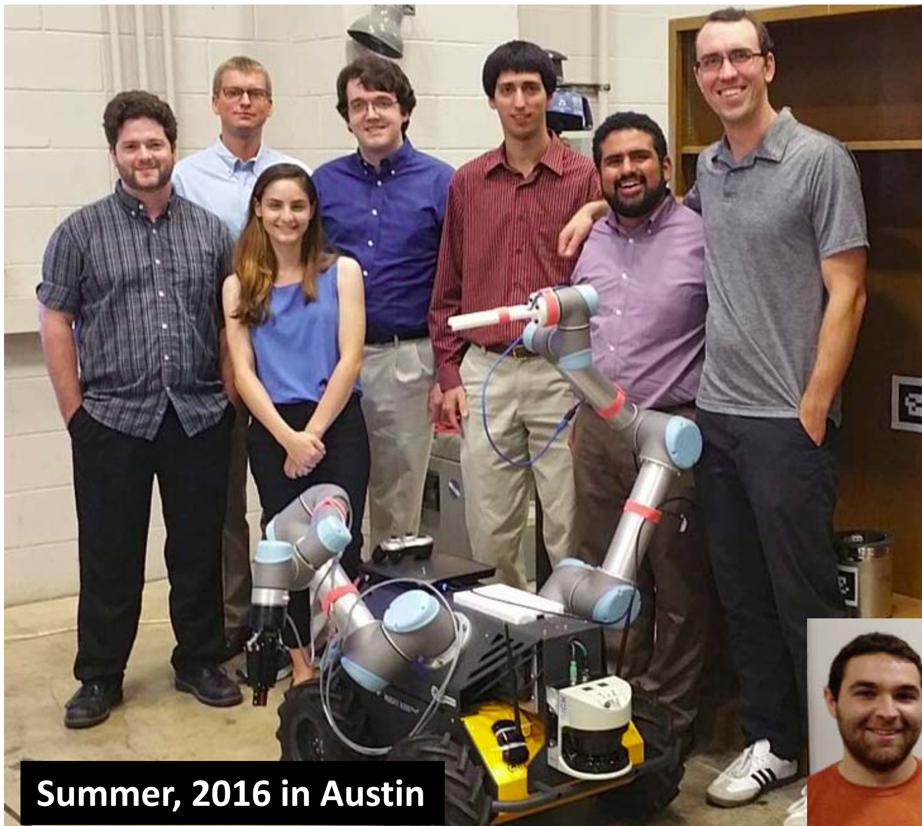
- The next steps
  - Design of a penetrometer for robotic NDT Systems
    - Larger than typical beam port
    - Off-axis characteristics
    - Include Seams
    - Evaluate film vs digital systems
  - Real-time control loop for seam detection and alignment.
  - Portable NDT
    - Explore other NDT applications
    - Sensor evaluation for performance and portability.

Enabling Technology



- **The technology enabling pipeline for DOE**
  - 15 Students joined since 2008 (7 graduated)
  - 5 full-time employees (3 PhD and 2 MSE)
  - 3 full-time student affiliates & 4 summer interns
  - 8 graduate students in pipeline at UT Austin
- **Deployment Highlights**
  - Robotic systems for manufacturing and assembly are operational in cold lab at LANL
  - Robotic system operational at UT Austin for material reduction. Delivered to LANL.
  - Mobile systems for inspection/inventory operating at both UT Austin and LANL
  - Robotic system demonstrated for NDT tested at LANL and at UT's 1MW reactor
  - Multiple packages released into the ROS and ROS-Industrial ecosphere
- **Academic**
  - 4 PhDs completed (+1 more this semester), 9 Masters completed (+2 more this semester)
  - Recent publication record: 15+ academic publications in last 2 years
  - 3 NEUP Fellowships, 5 NRC Fellowships, 7 DOE/ANS paper/poster awards
  - 10+ undergraduate researchers and 40+ undergraduates completed LANL sponsored senior design projects.

Special thanks to these folks… and you.


Summer, 2016 in Austin

Summer, 2016 in Los Alamos


2016-17 New Students