Smart Robotic Assistants for Manufacturing Applications

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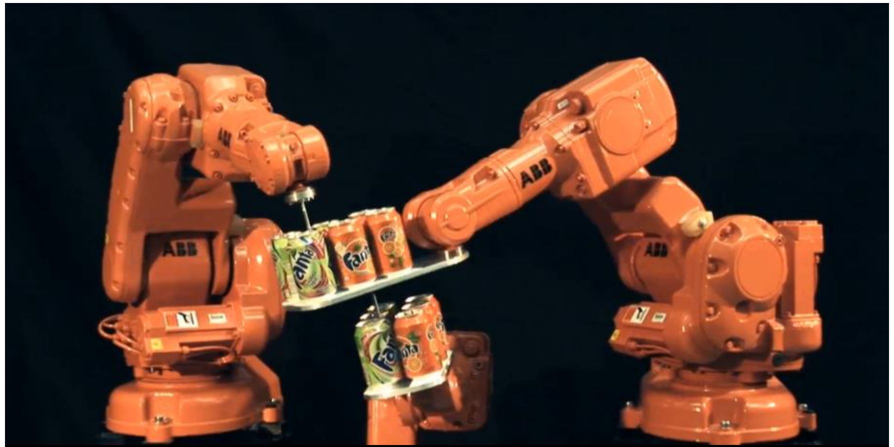
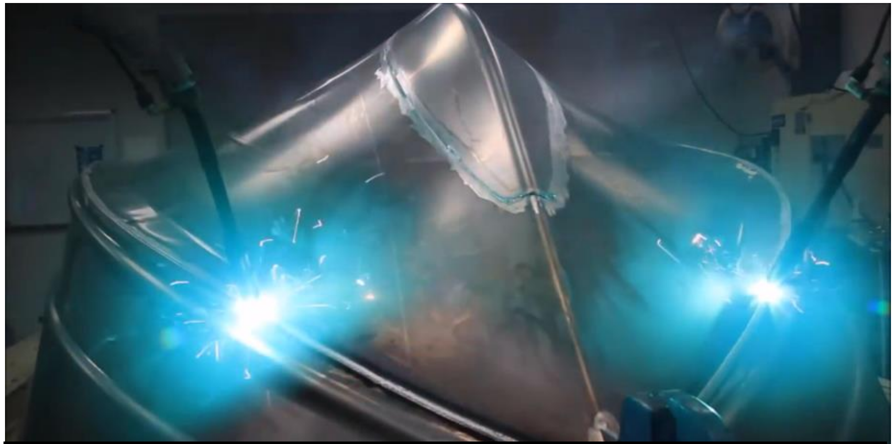
Industrial Robots Today

Source: https://www.youtube.com/watch?v=8_lfxPI5ObM



Source: https://www.youtube.com/watch?v=SOESSCXGhFo

Source: https://www.youtube.com/watch?v=NAqm5_jk2ws



Source: https://www.youtube.com/watch?v=CigVLW4M4-I

Robots are physically capable of performing highly complex tasks

Limitations of Industrial Robots

- Need human experts to program robots
- Configuring a robotic cell for a new task takes significant time and effort
- Robots repeat preprogrammed motions and cannot automatically adapt to changes in the workspace or tasks
- Recovering from errors requires significant downtime and can be very expensive

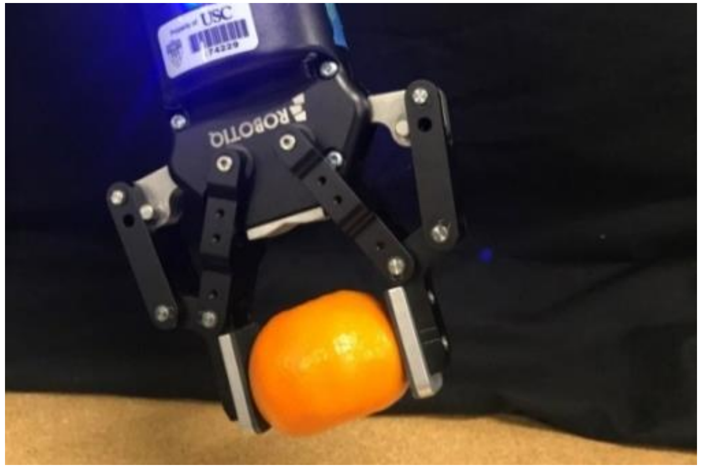
Source: http://www.fanuc.eu

Robots are largely used in mass production applications.

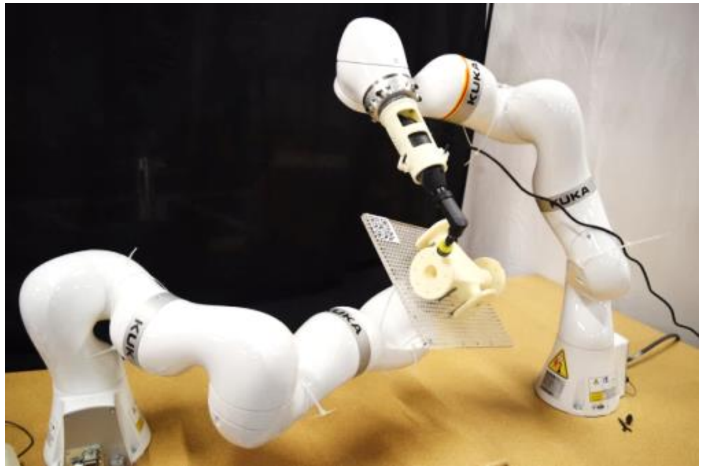
Less than 2.5 robots for every 100 manufacturing workers in US.

Recent Advances in Robotics

Stereo Vision
Force Sensing
Tactile Sensing



Impedance Control
Visual Servo
Shape Control



Multi-Arm
Manipulation

Mobile
Manipulation

Relying on humans to program industrial robots is not a viable option as robotic cells get more complex

Advent of Collaborative Robots

- Humans and robots have different strengths
  - Humans are highly capable in dexterous tasks and perception
  - Robots can apply large force, operate at high speed, and be highly repeatable
- Collaborative robots can work in close physical proximity of humans

https://ifr.org/members-news/suppliers/skoda-auto-matador-group-and-kuka-ending-the-separation-of-humans-and-rob/

Collaborative robots can serve as assistants for humans

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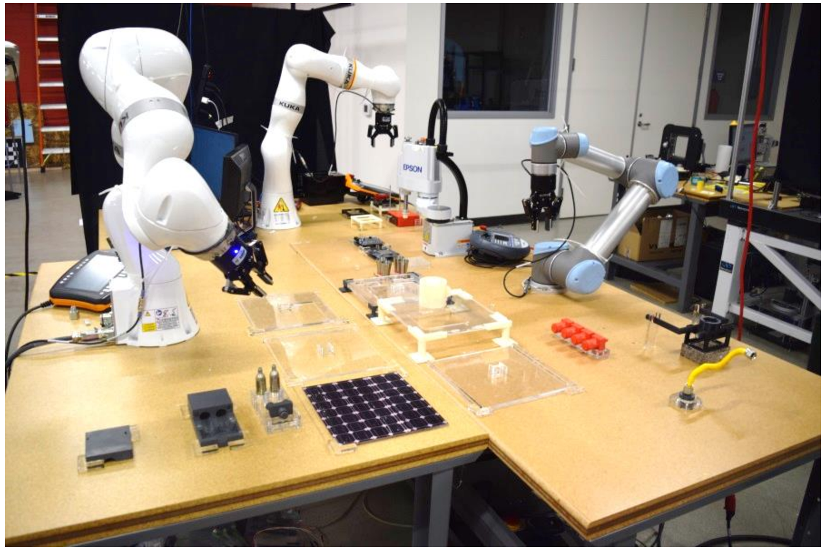
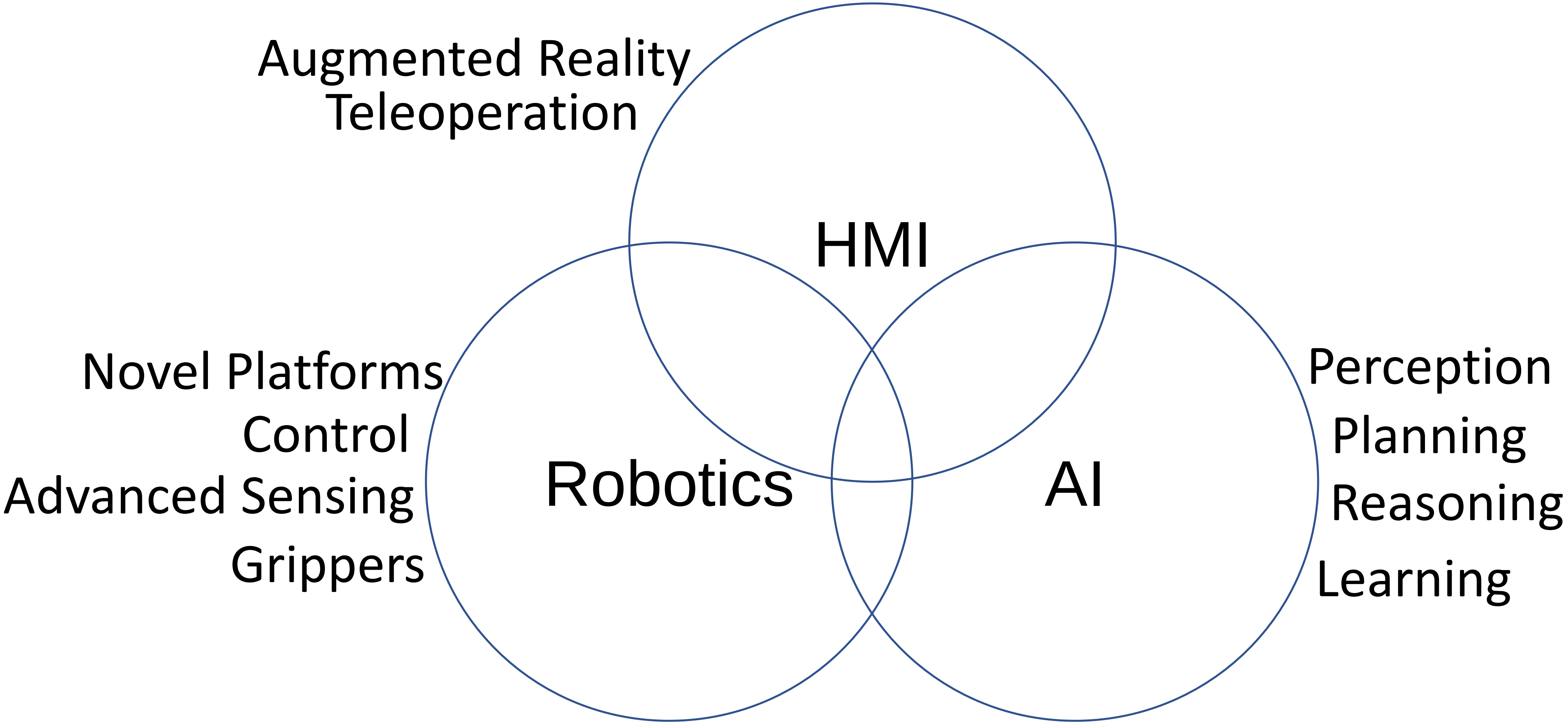
We Need Smart Robotic Assistants

1. Robots that can program themselves
2. Robots that can learn by conducting experiments
3. Robots that can ensure safe execution under uncertainty
4. Robots that can seek help from humans
5. Robots that can effectively communicate with humans

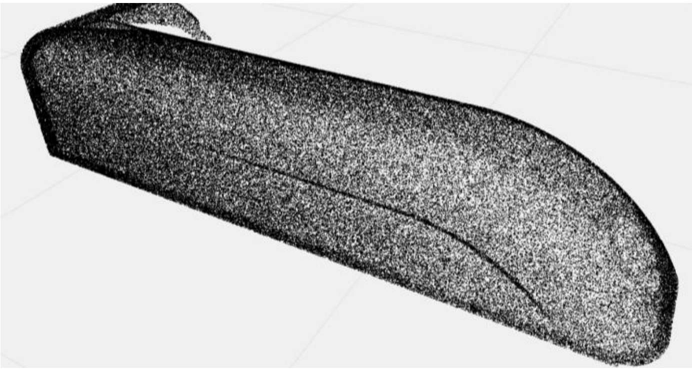


Smart Collaborative Robots



Capability #1:
Robots that Program Themselves

- Agility and reconfigurability requires robots to program themselves from task descriptions
- Integrated task and motion planning
- Real-time computation of near optimal trajectories for high degree of freedom systems
- Learning-aided trajectory planning



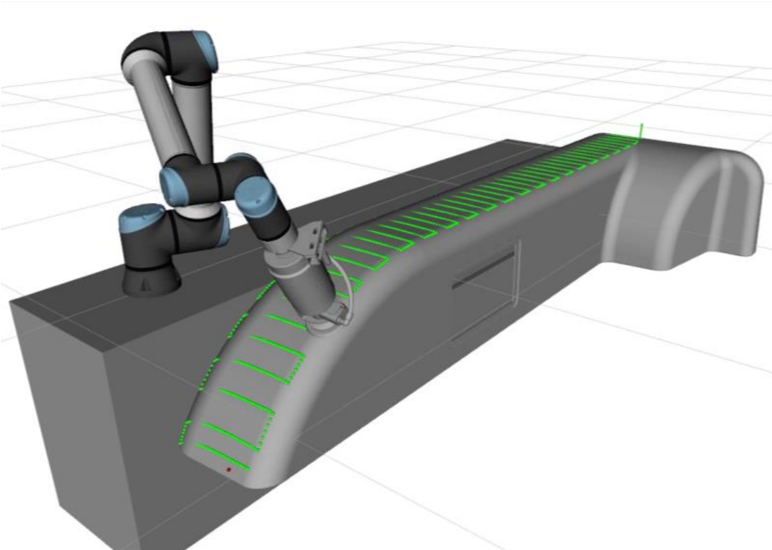


Image Source: Gray Matter Robotics

Capability #2:
Learn by Conducting Experiments

- Task performance model may not be known *a priori*
- Robots need to conduct experiments on their own and adapt task performance model during task planning and execution
- Self-supervised learning to efficiently complete the given task

Image Source: Gray Matter Robotics

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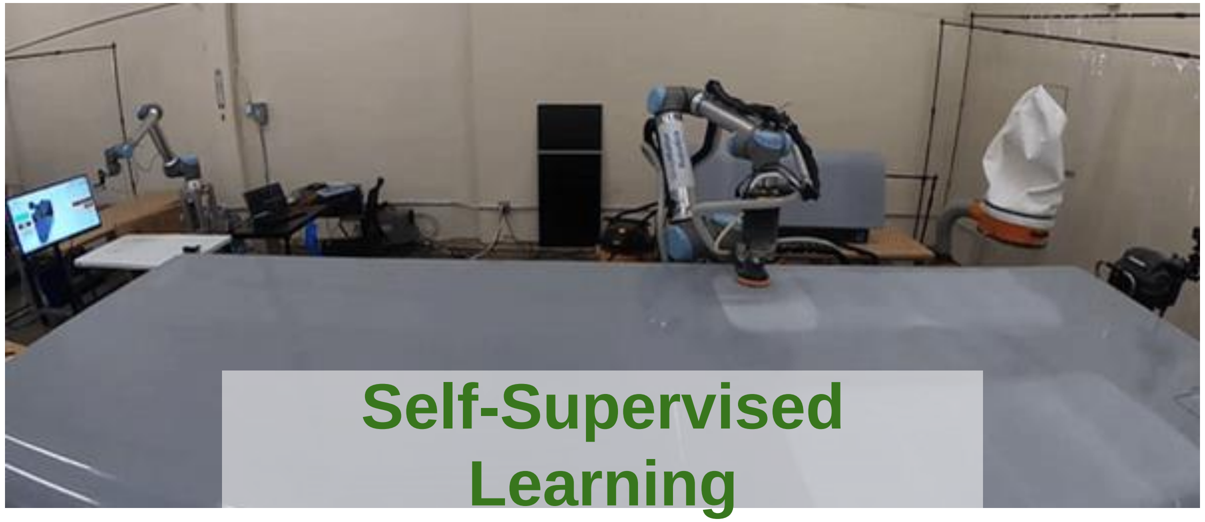
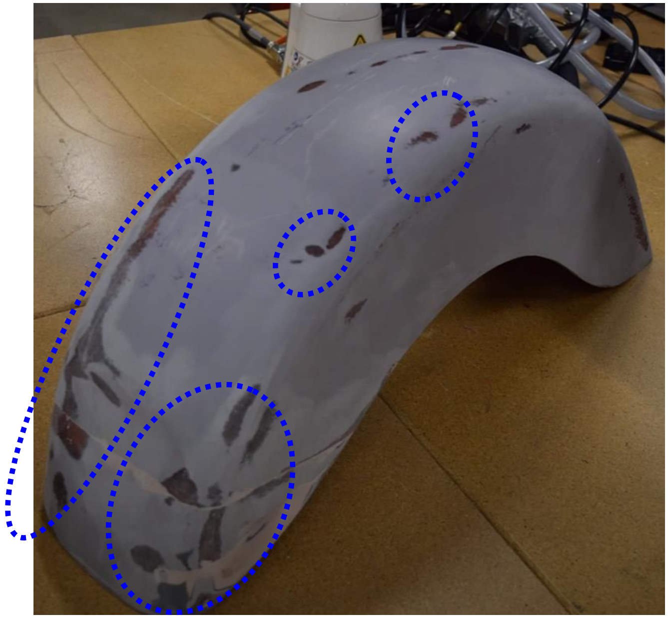


Image Source: Gray Matter Robotics

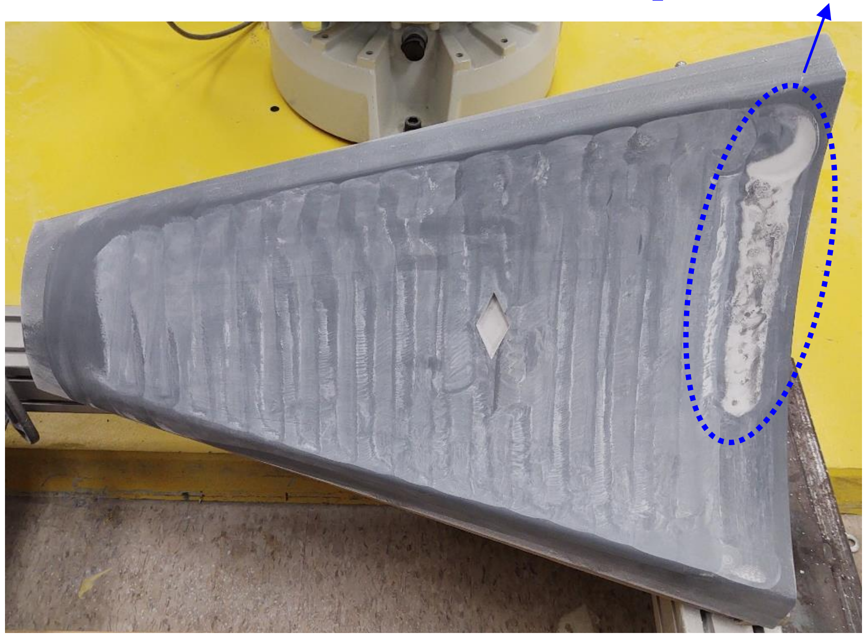
Consequence of Constraint Violation During Task Execution

- Different kinds of constraints lead to different constraint violation consequences

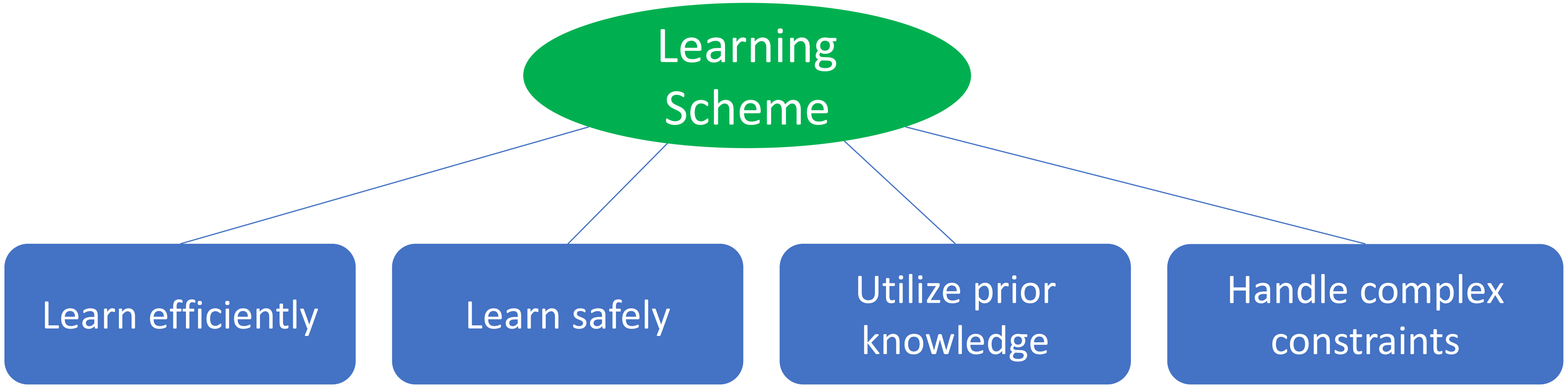
Quality constraint is not met:
Redo the task



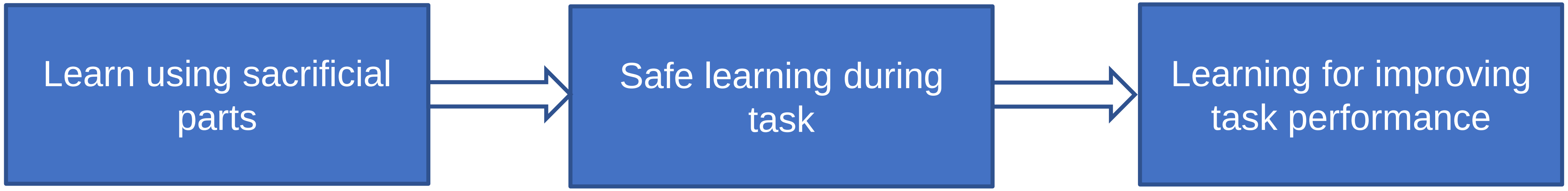
Part damaged:
Replace the whole part



Requirements



A Hybrid Learning Strategy



Establish initial safe region to explore

Establish parameter limits to avoid safety violations

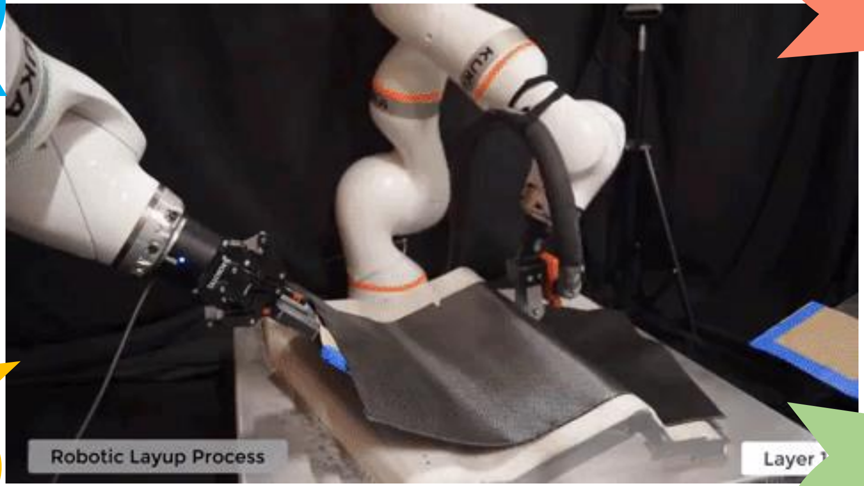
Determine parameters to complete the task

Our goal is to complete the task efficiently and safely;
We are not interested in finding the most complete process model

Utilizing Prior Knowledge

Known ranges of parameters

Qualitive effects of parameters on performance



Similar task execution

Known safe parameters that will not cause fatal damage

Idea Behind Approach

- Combination of GPR and Neural Networks for representing underlying process models
- Enforce known qualitative constraints on underlying models
  - E.g., increase in parameter *x* leads to increase in parameter *y*
- Bound uncertainties using physical constraints
- Use Monte Carlo Tree Search to consider effect of future exploratory actions
- Use transfer learning to establish safe regions

Capability #3: *Safe Execution Under Uncertainty*

- Agile and rapidly reconfigurable robot cells cannot use custom fixtures to reduce uncertainty
- Robot should not apply excessive force on objects or cause excessive deformation
- Robot should not make unwanted contact with the objects in the environment
- Learn to adapt trajectories to ensure safe execution under uncertainty

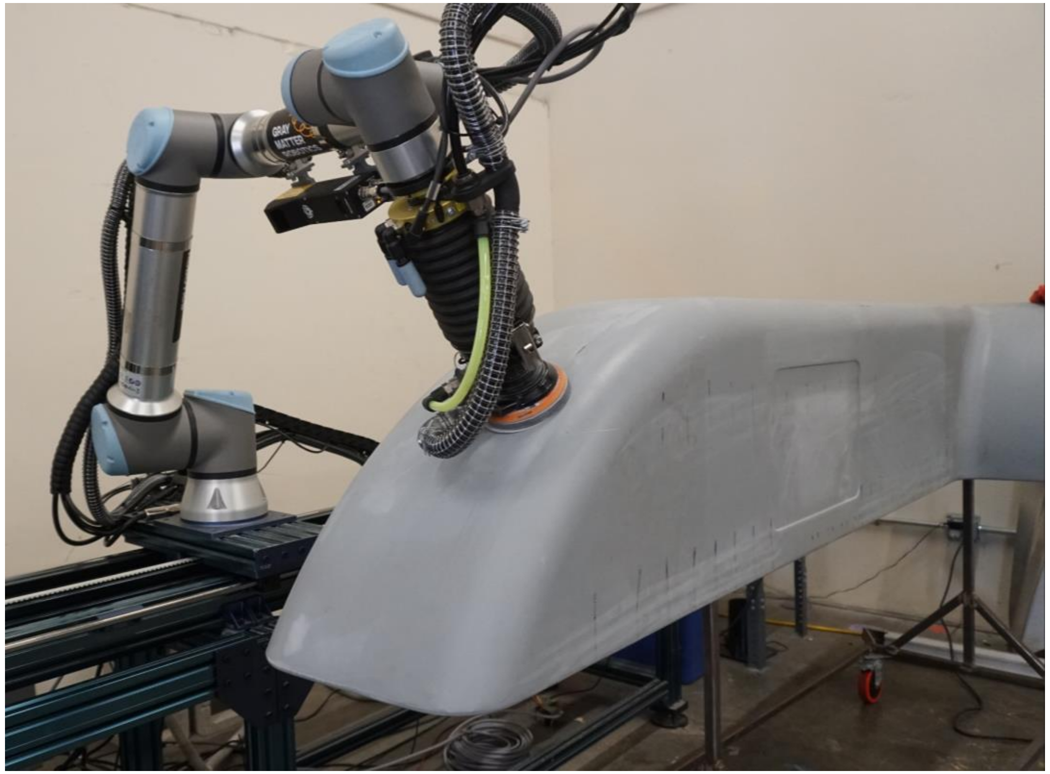
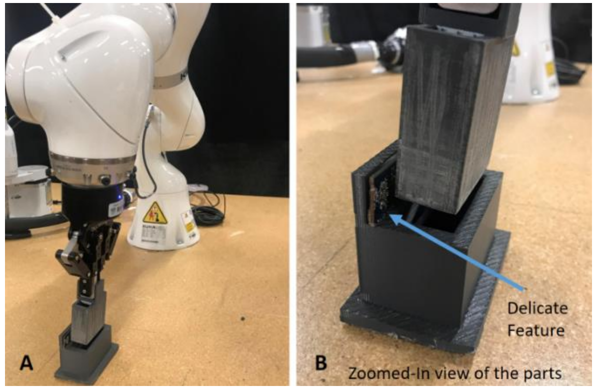


Image Source: Gray Matter Robotics

Examples

- Contact-based probing with safety constraints
  - Generate trajectories to reach contact points safely under the estimated uncertainty
- Safe insertion under large uncertainties
  - Select parameters of impedance controller to avoid contact with delicate part features
  - Use machine learning on force feedback from robot to generate optimal search strategy for determining the insertion location

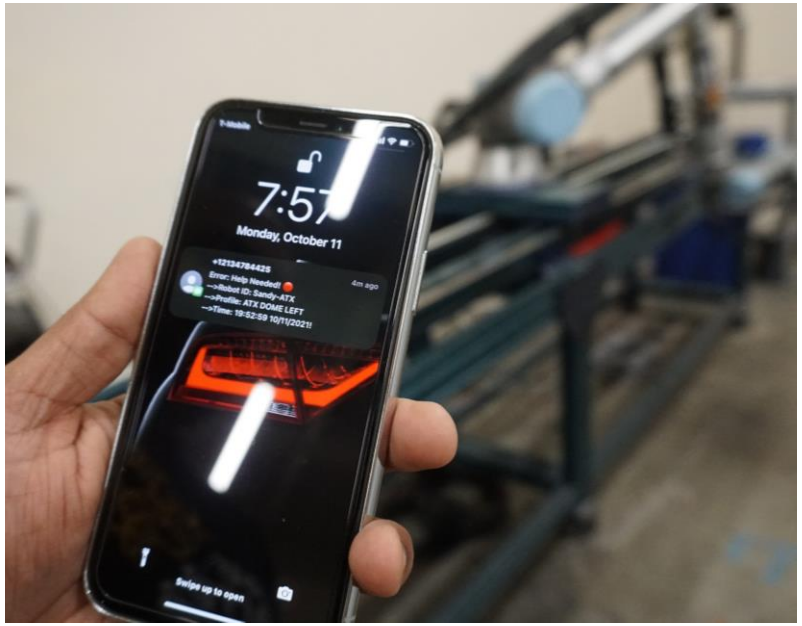
Human-robot collaborative cell for fixtureless assemblies



Assembly of a rectangular peg in a hole problem

Capability # 4:
Robots that Seek Help from Humans

- Introspection to estimate robot task completion confidence and consequence of task completion failure
- If the task completion confidence is low, then the system should seek help from the human



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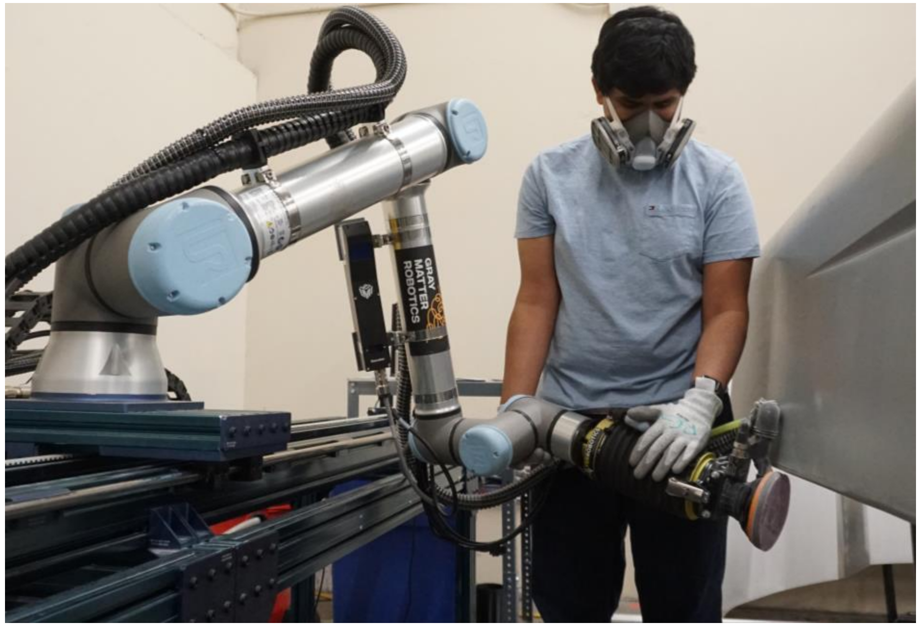
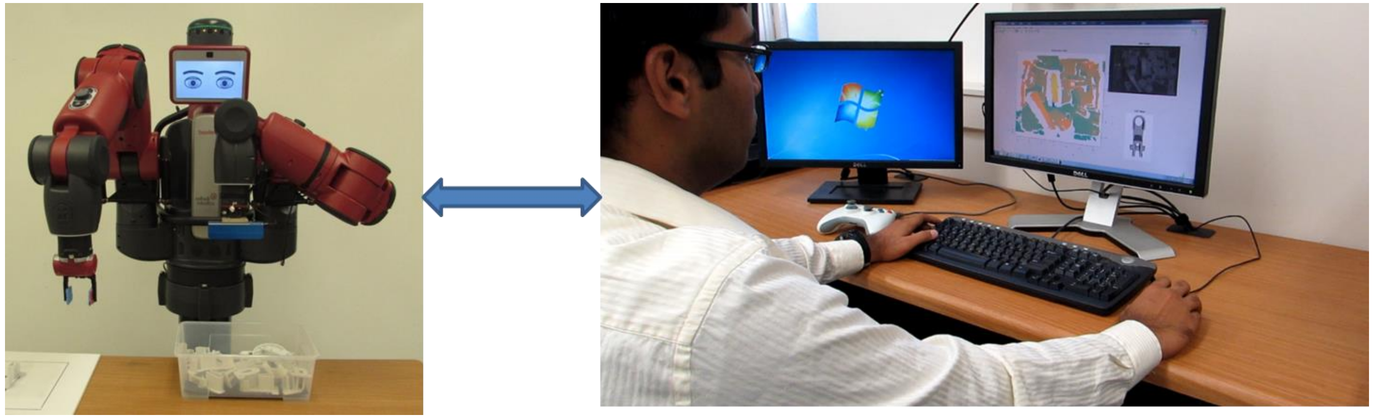
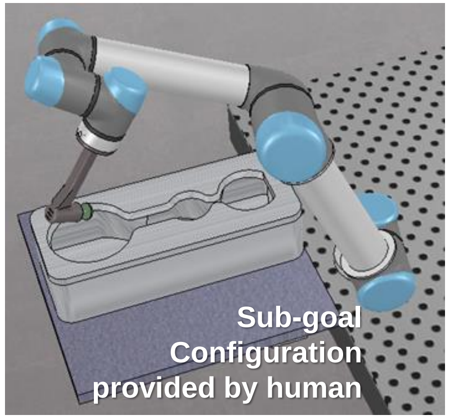


Image Source: Gray Matter Robotics

Examples

- Real-time tool-state monitoring based on task performance changes
  - Request for tool change
- Identification of infeasible motion planning problem instances
  - Request for setup change
- Prediction of trajectory/setup planning failure
  - Request for human guidance during planning
- Estimation of plan execution risk
  - Request for human help to reduce part uncertainty





Capability #5:
Communicate Efficiently with Humans

- Robots need to be tasked by humans
- Robots need to elicit help from humans to handle challenging tasks
- Context-dependent level of detail control to prevent cognitive overload for humans
- Augmented reality-based interfaces for robotic cells to facilitate information exchange between humans and robots

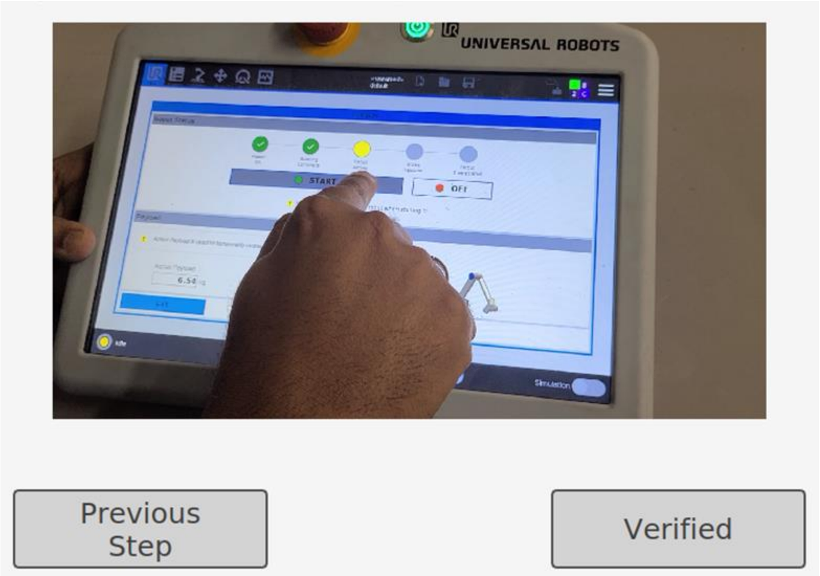


Image Source: Gray Matter Robotics

Examples

- Augmented reality-based interfaces for robotic cells to facilitate information exchange between humans and robots
  - Display safety zones
  - Confirm instructions given by humans
  - Display errors and warnings
  - Display internal system states and enable humans to diagnose problems
- Context-dependent level of detail control to prevent cognitive overload for humans

Trustworthy Smart Robotic Assistants

- Unambiguous Communication
- Ability to Explain Decision Making Rationale
- Consistency
- Predictability

Need for Innovation in Interfaces

- Cars needed steering wheels
- Computers needed keyboard and mouse
- Smart phones needed touch screens
- TVs needed remote
- Video games needed Wii Mote and Kinect

http://www.newscientist.com/blogs/onepercent/2012/01/09/rexfeatures_1460534o.jpg

http://sclick.net/cool%20gadgets/funny-top-newest-high-tech-electronic-gadget/13/top-cool-latest-new-best-gadgets-wii-active-playing.jpg

Observations

- Interfaces have been adopted from other applications
- Model of humans interacting with each other might not be the best model for human robot interaction
  - Current generation of robots “thinks” differently from humans
  - Advances in statistical machine learning will lead robots to process information in a fundamentally different way from humans

Innovations in human-machine interfaces will be a key to building trustworthy robotic assistants

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Learning and Trust Building

Physics-Informed Learning

- Learn efficiently
- Learn safely
- Utilize prior knowledge
- Handle complex constraints

Learn using sacrificial parts → Safe learning during task → Learning for improving task performance

- Learn using sacrificial parts: Establish initial safe region to explore
- Safe learning during task: Establish parameter limits to avoid safety violations
- Learning for improving task performance: Determine parameters to complete the task

Trust building needs to be a key criteria in designing learning paradigms

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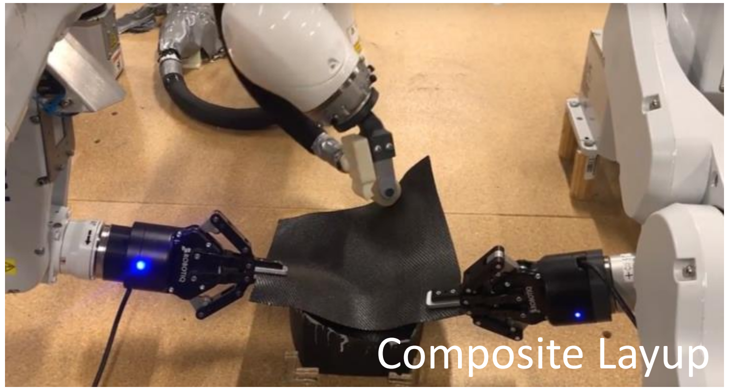
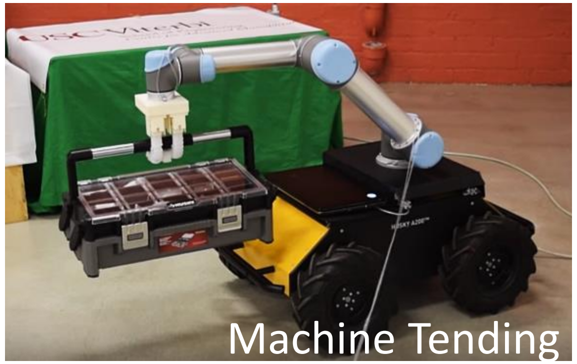
Manufacturing Applications


Bin Picking and Kitting


Finishing


Collaborative Assembly


Composite Layup


Machine Tending


Additive Manufacturing

Inspection

Publications

https://sites.usc.edu/skgupta/publications/

Videos

https://www.youtube.com/channel/UCO82Tsg5Xc5vP_ZWkax4Wpg