NRI: FND: Human-Guided Robot Teams for Manipulating Large Flexible Sheets in Manufacturing Applications

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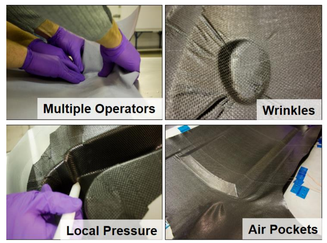
Motivation

- Composite materials provide high strength to weight ratio
- Layup of prepreg sheets is one of the main processes for realizing composite parts with complex geometries
- Sheet layup process requires significant manual labor
- Sheet layup automation can reduce ergonomic challenges and increase process throughput

Ongoing Layup
(Source: Modernmachineshop 2018)



Characteristics and Defects

Planning and Control For Sheet Manipulation

Formulation for Coordinated State Space Search

- Develop an energy-based method for simulating the sheet
- Develop cost function to evaluate quality of sheet states
- Efficiently solve grasp sequence search
- Use gradient descent-based ordering heuristics to expand nodes in graph

Human Guidance During Search

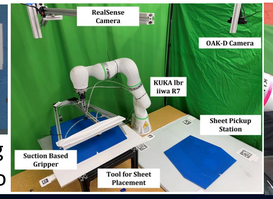
- Develop GUI for human input
- Obtain domain knowledge to truncate state space

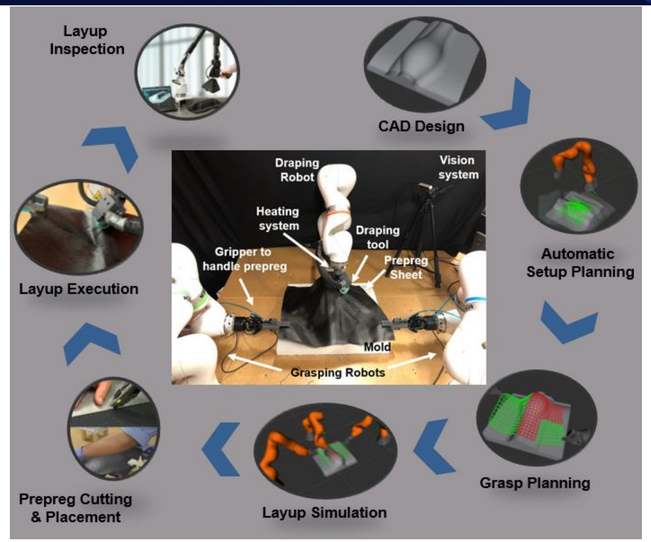
Visual Servo-based Control

- Use position control with inverse Jacobian scheme to accurately control the position of the sheet
- Develop Jacobian estimation that leads to faster convergence for aligning the sheet with the final desired state

Initial Sheet Misalignment

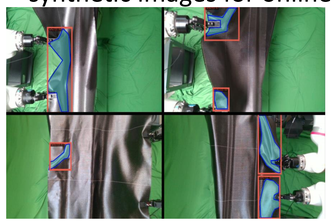
Alignment using Fast Visual Servo





Execution Monitoring and Defect Detection

- Fast and accurate automated cell calibration
- Preventing defects through contingency maneuvers
- Planning for rework and recovery from errors
- Safe and efficient human intervention during execution
- Using deep learning-based defect detection framework trained on synthetic images for online detection and repair



Deep learning network is trained using more than 10000 synthetic and 1000 real images to achieve an online detection accuracy of 98%

Contingency maneuver as an optimal pull direction prevents defects from occurring

Goals

- Develop deliberative planning algorithms for collaborative manipulation by proactively accounting for interventions by controllers and humans during execution to handle contingencies
- Develop algorithms for monitoring of the task progress during the execution and initiating interventions to ensure safe and efficient operation
- Demonstrate approaches developed to meet the first two objectives on the composite layup application
- Integrate research results with manufacturing and robotics courses

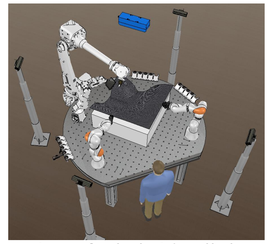
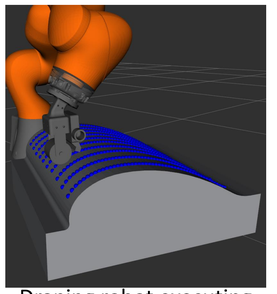


Illustration of a hybrid cell that can be used for composite sheet layup

Path Constrained Trajectory Planning For Draping Robot

- Use multiple TCPs and tolerances to find low-cost trajectories and improve success rate
- Use graph-based planning by approximating constraint manifold in configuration space
- Sequentially progress using a workspace heuristic to bidirectionally generate sub-graphs in configuration space
- Develop a cost map for all nodes in source and sink to bias future samples
- Machine learn the exploration and exploitation profile for biasing



Draping robot executing paths under motion constraints in simulation

Broader Impacts

- Introduce robotics in small volume operations and make manufacturing cost competitive in the US
- Enhance robotics and manufacturing curricula by incorporating research results into graduate and undergraduate courses
- Engage students from underrepresented minority groups and undergraduate students in research
- Outreach activities for K-12 students to educate and inform them about career opportunities in robotics and manufacturing

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