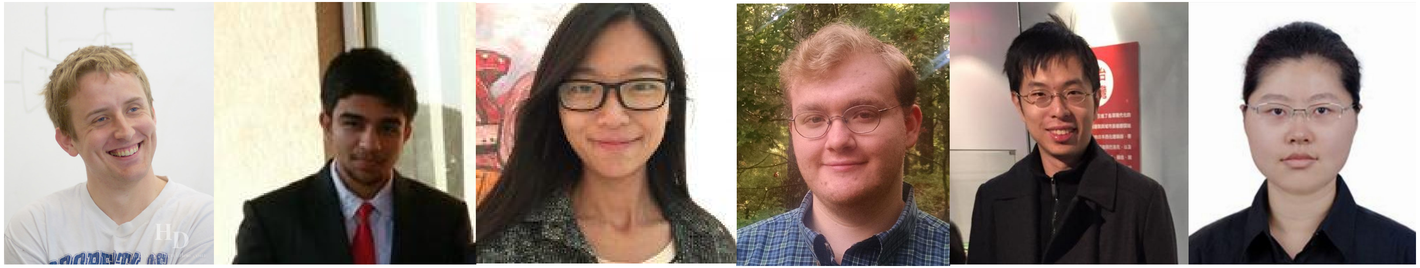
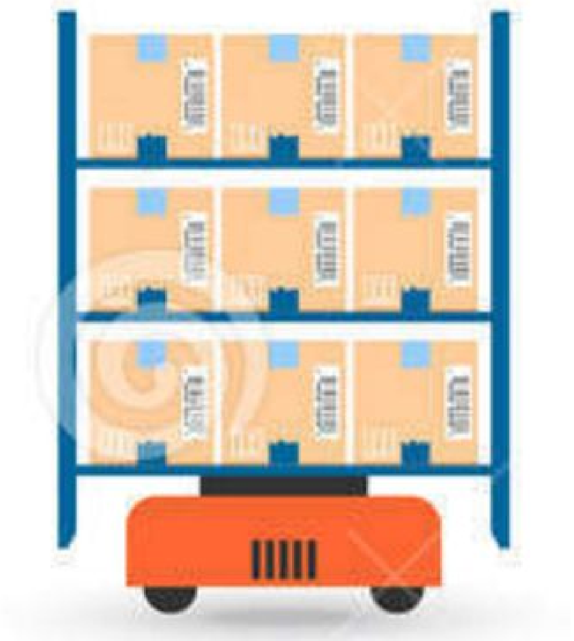
TEAM PLAID

Michael Beck, Akshay Bhagat, Sharon Jin, Matt Lauer, Che-Yen Lu “Leo”, Jin Zhu



Project Description



Provide a solution for repetitive warehouse materials handling by bringing an autonomous picker/stower to life.

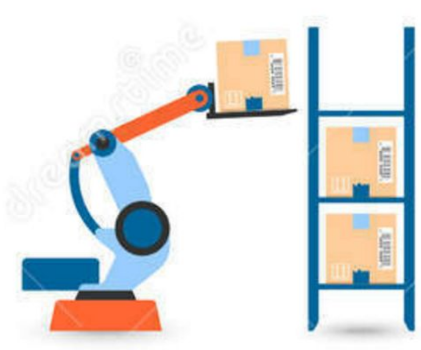
https://www.dreamstime.com/stock-illustration-warehouse-robots-icons-set-loading-unloading-flat-vector-illustration-image63821007

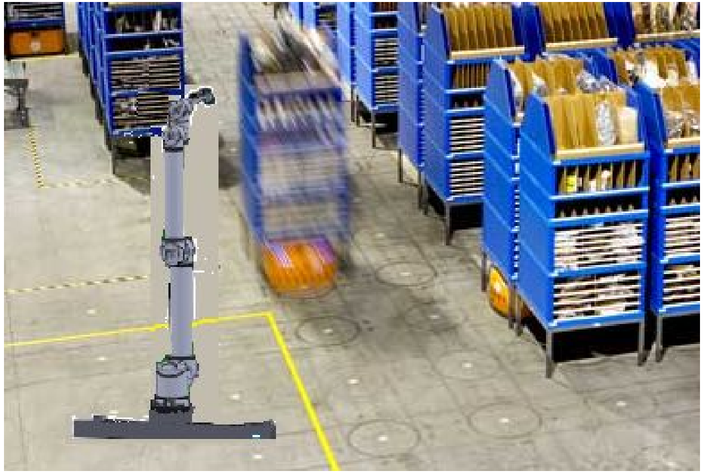
Project Description Cont'd

- Competing in the Amazon Picking Challenge at RoboCup, July 2017
- Bot must pick and stow items within an allotted time
- Unknown item classes have been added to the competition
- Competition heavily emphasizes accurate item location reporting

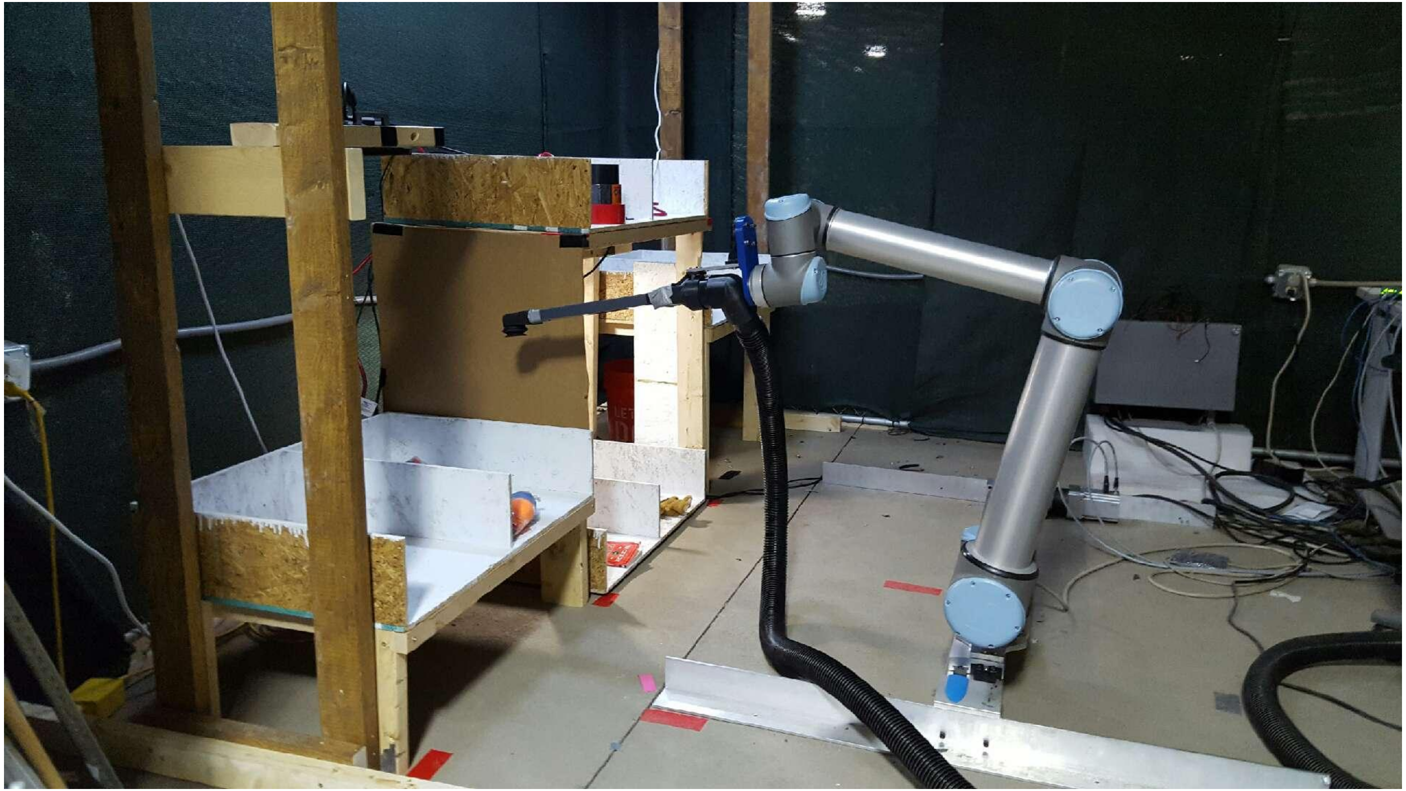
Use case

- Warehouse owner wants to cut costs
- The owner decides to buy our robot
- The robot picks and stows accurately
- The efficiency of the warehouse increases

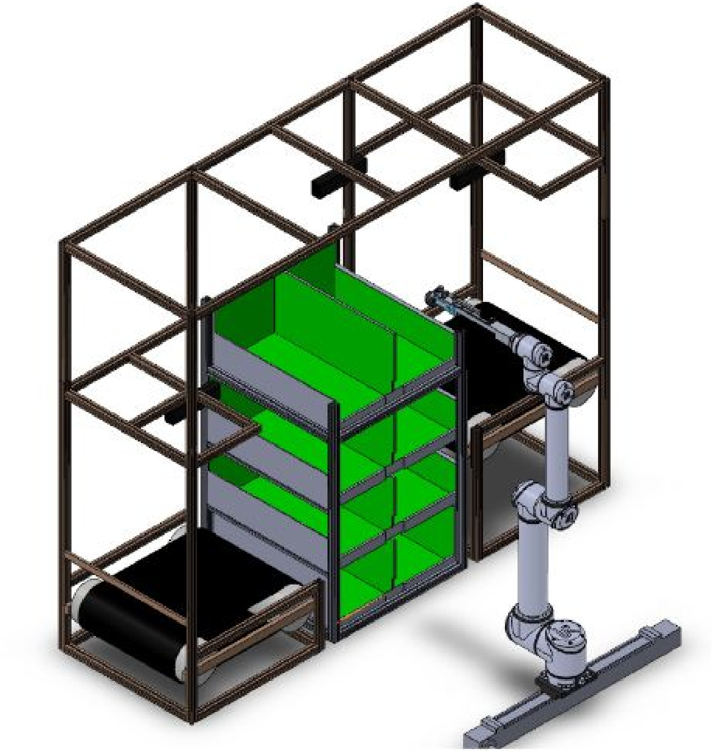




Use Case



System Design - Original



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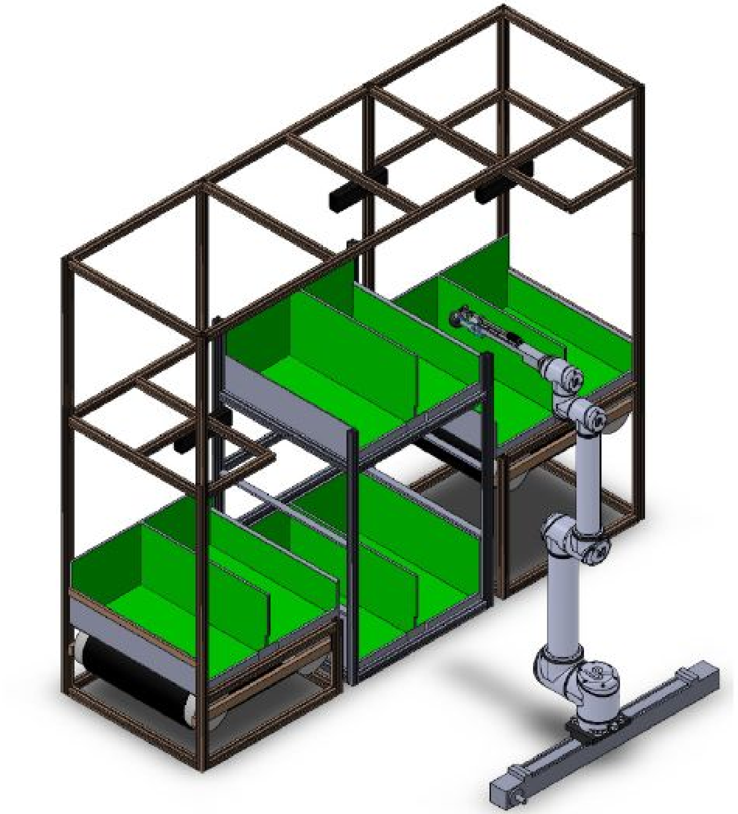
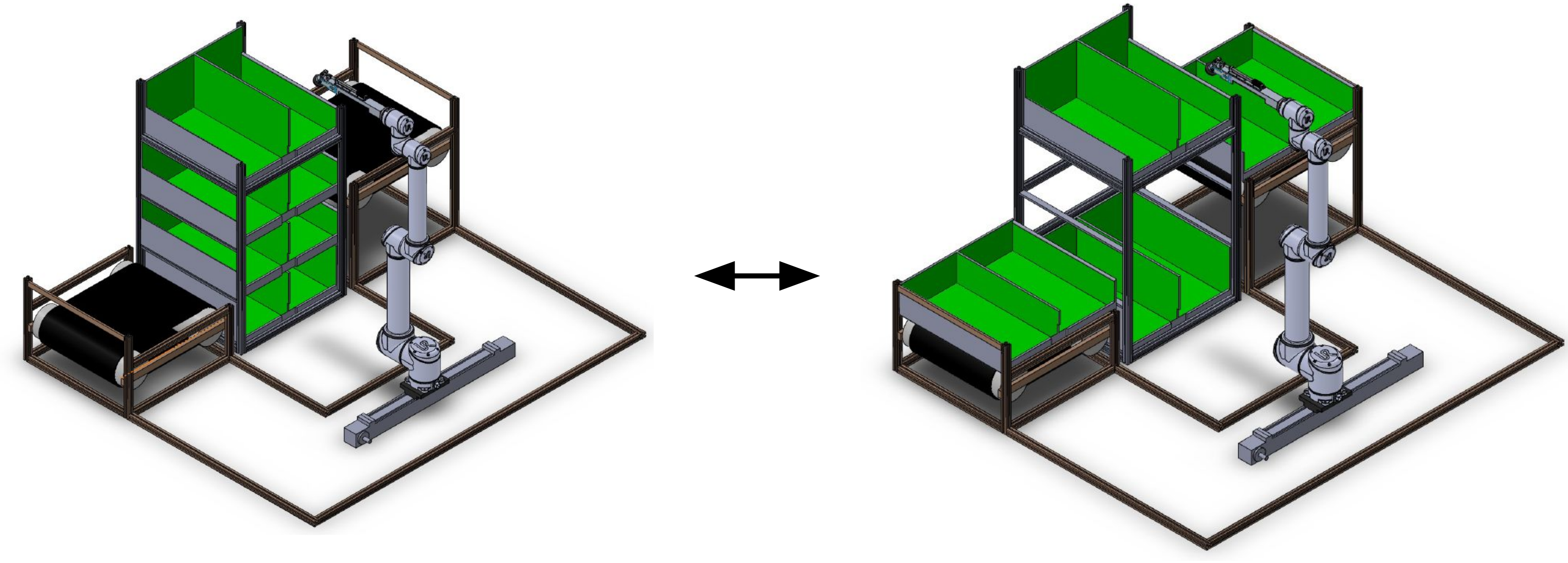
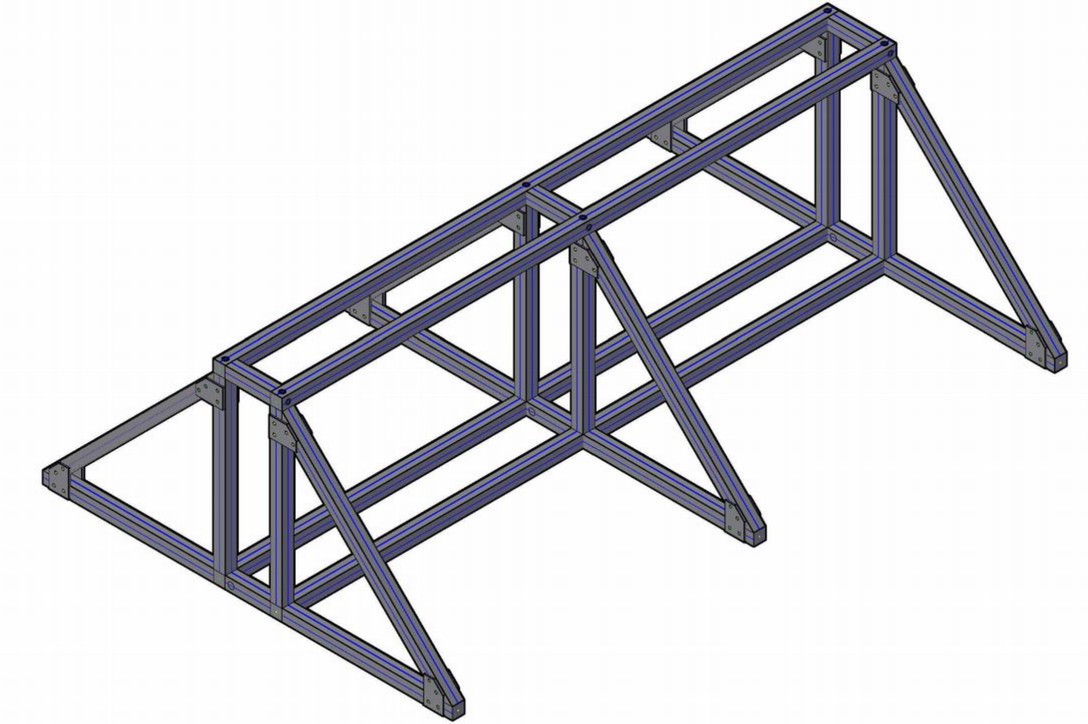


System Design - Reduced Complexity



System Design - Arm Stand



System Design - Challenges

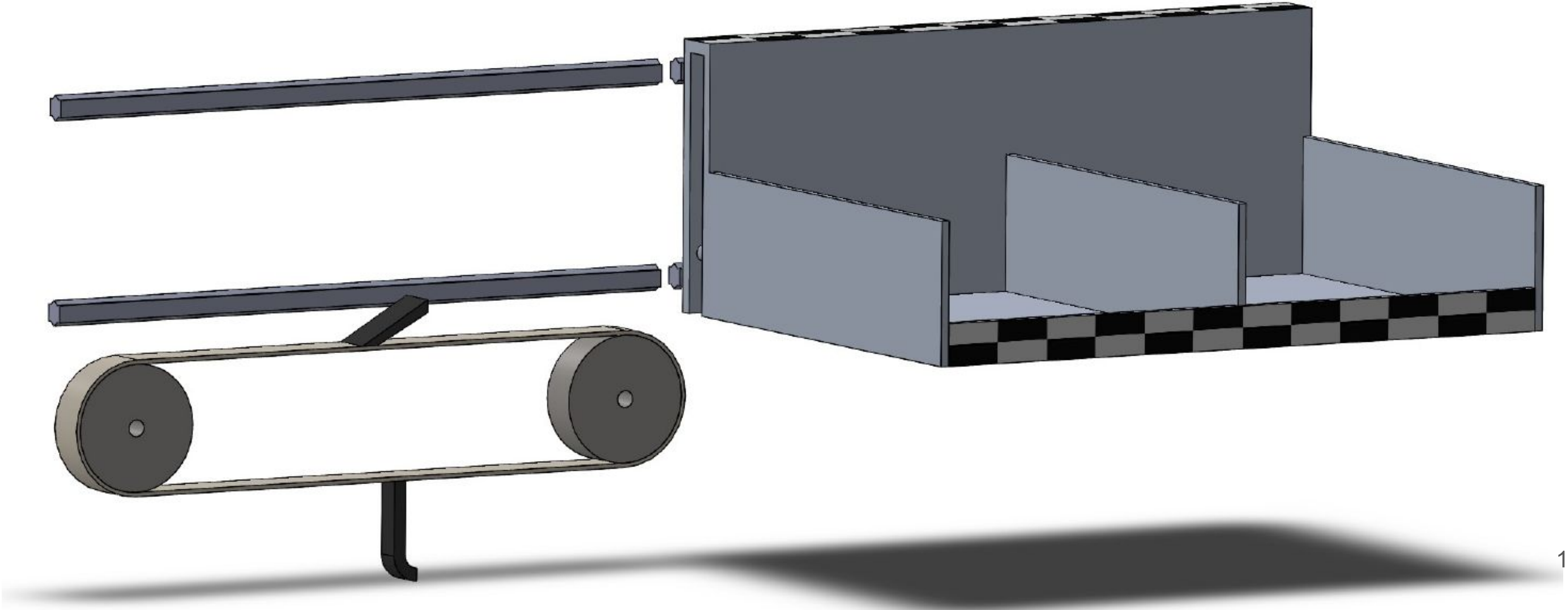
Multiple Sensors:

- Hardware restrictions
- Budget concerns
- Timesink

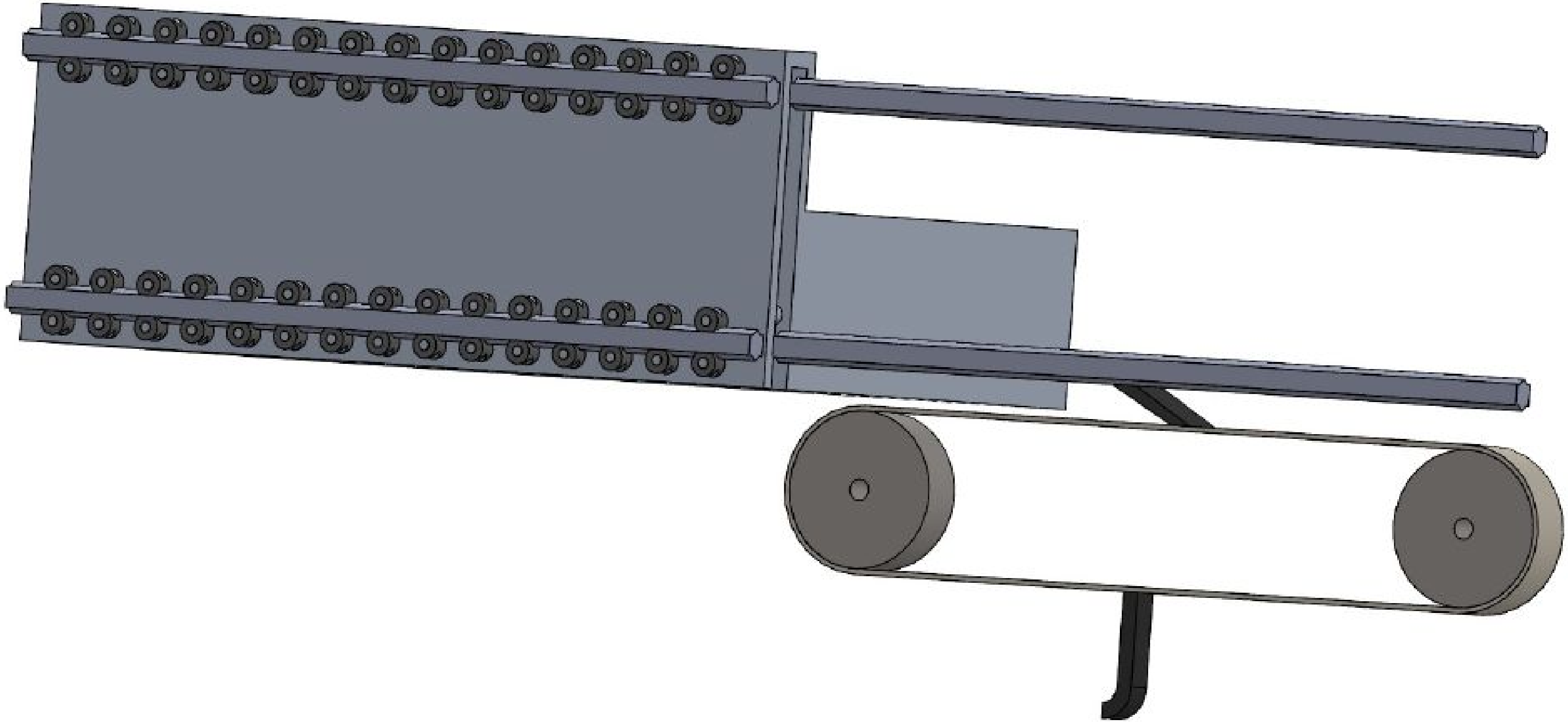
Shelf - Functional Description

- 4 drawers, with each drawer having 2 bins (8 bins total)
- 125cm height x 80cm width x 62.5 cm depth
- DC motors and limit switches actuate drawers
- Top and bottom drawer are stationary, middle drawers are on sliding rails
- Drawers are pushed back and forth by leaf springs attached to a chain drive

Shelf - Actuation (Front View)



Shelf - Actuation (Back View)



Shelf Current Stage - Wooden Mockup

Shelf - Remaining Challenges

- Begin and finish fabrication
- Ensure smooth movement of drawer actuation and precision control
- Any issues yet-to-be discovered (priority task for this reason)

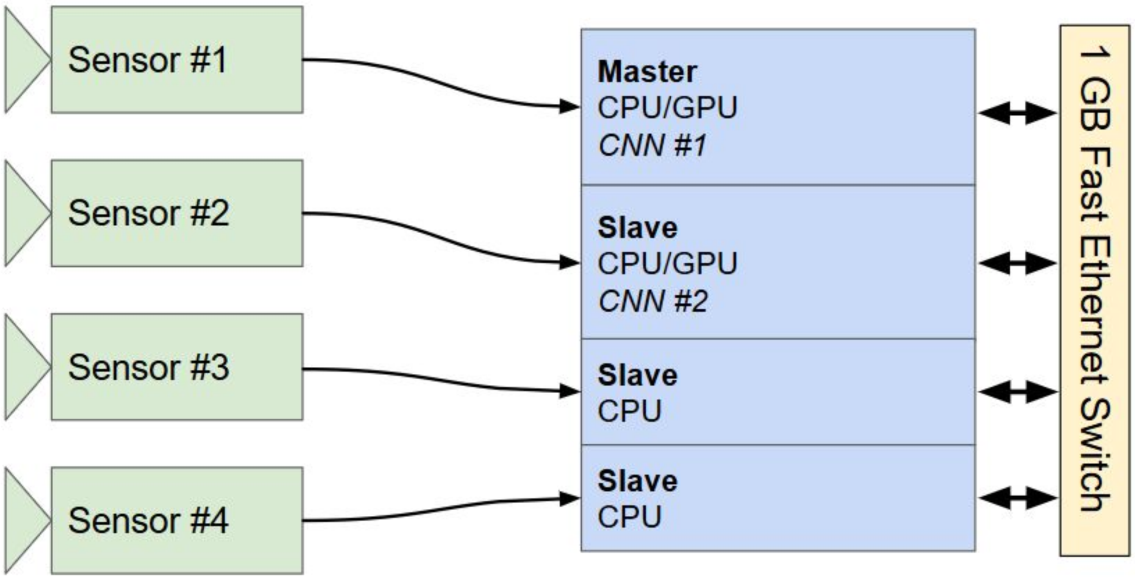
Vision - Functional Description

- Train image set on FCN and Faster-RCNN. FCN provides pixel-wise locations, Faster-RCNN validates FCN results.

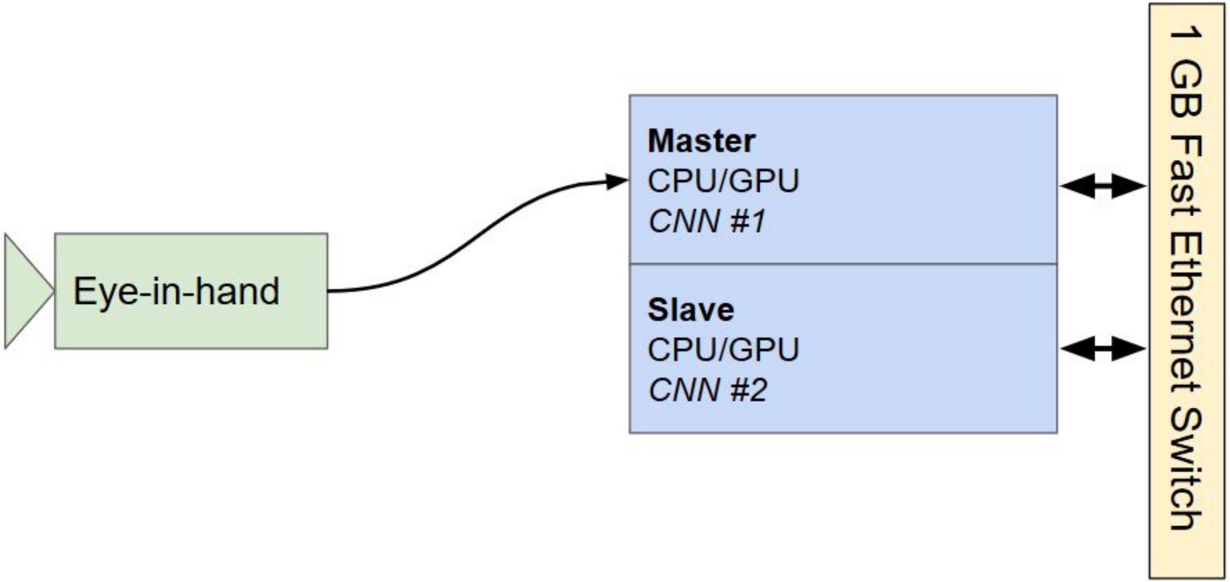
- Train a depth image CNN to recognize competition classes: Book, Box, Wrapped, Clamshell, Cylinder, Deformable, Other.

- Pass locations and classifications to PERCH. Output 6-DOF item pose or segmented point cloud as appropriate to grasping subsystem.

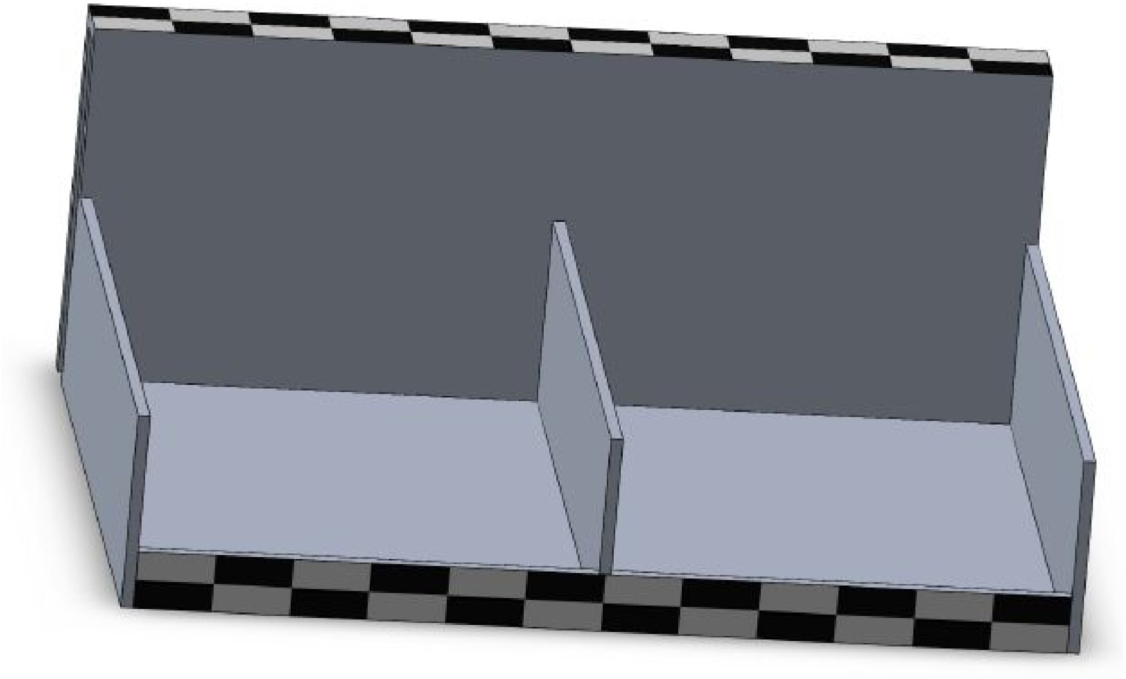
Vision - Original Hardware Design



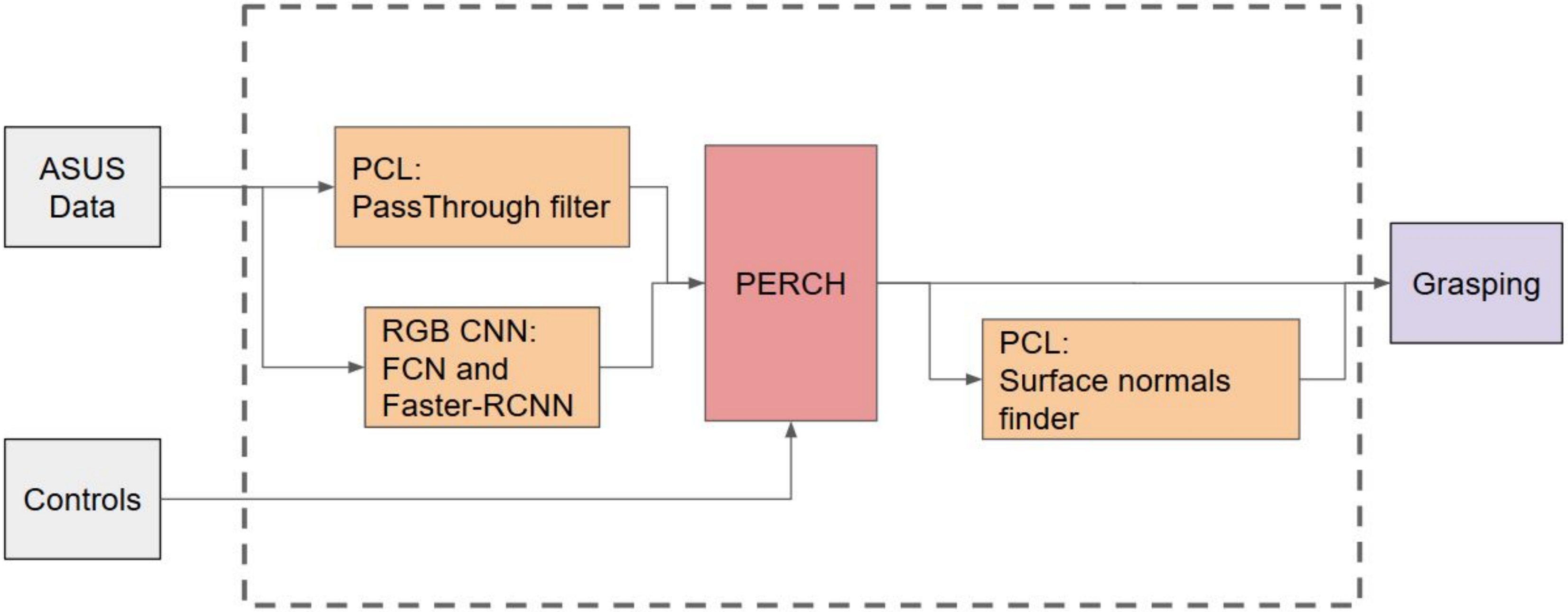
Vision - Current Hardware Design



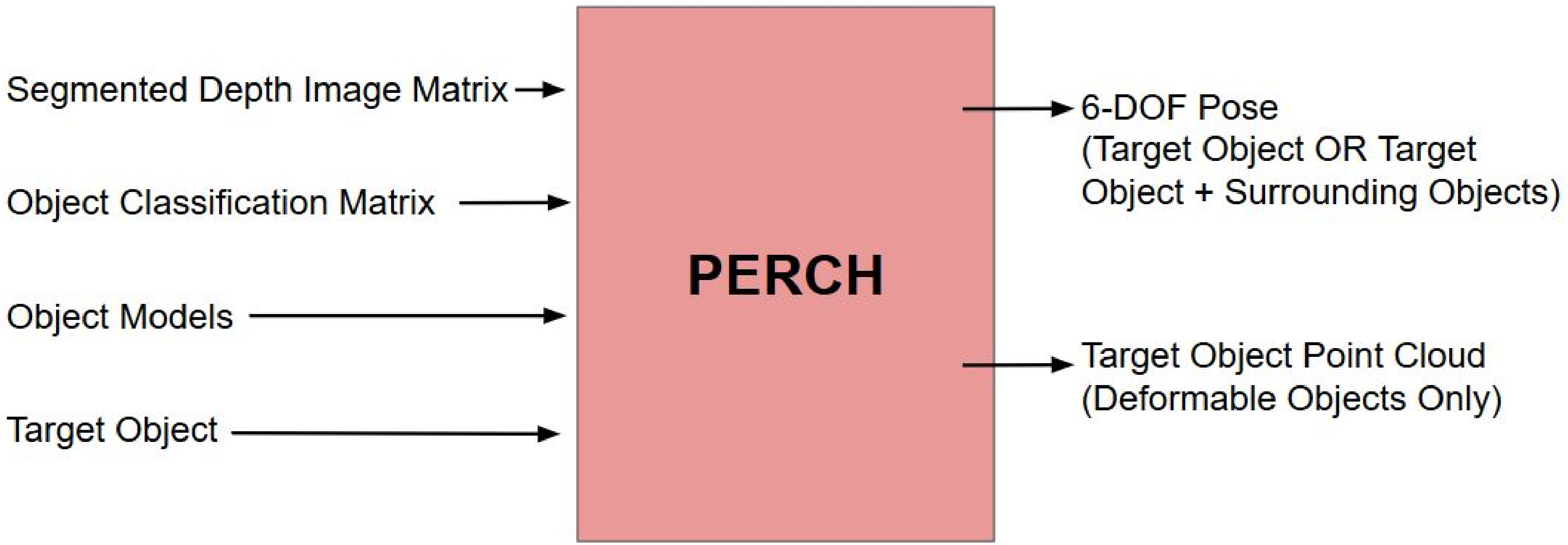
Vision - Shelf Hardware, Apriltags



Vision - Software Conceptual Diagram

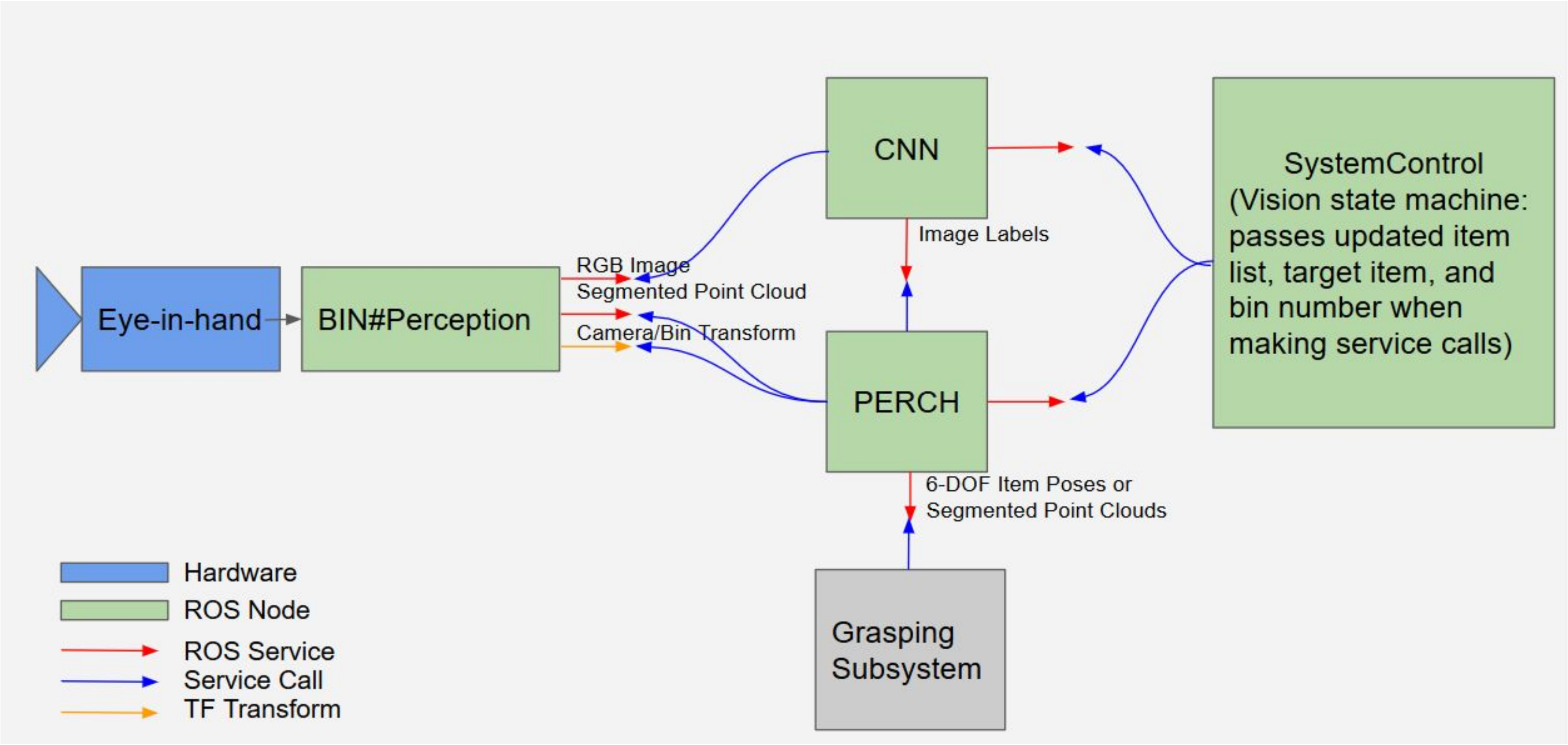


Vision - PERCH



Vision - Software Implementation

Put

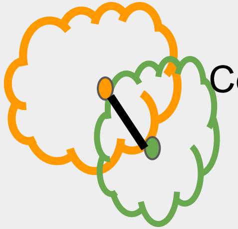


Comparison Metric

Labeled Images

Convolutional Neural Network (CNN)

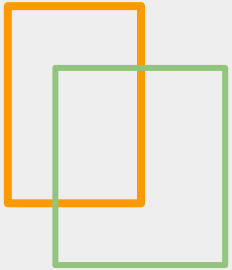
Metric 1: centroid offset



Centroid distance

A Ground truth pixelwise labeling
B Pixelwise output from CNN

Metric 2: Bounding box offset



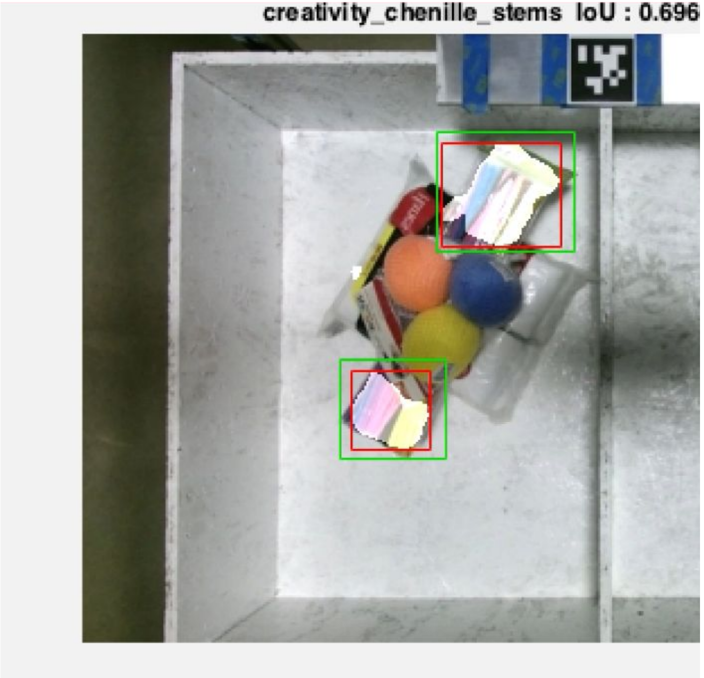
$$accuracy = \frac{A \cap B}{A \cup B}$$

A Ground truth bounding box
B Output bounding box from CNN

Comparison Result: Drift / scale inaccuracy

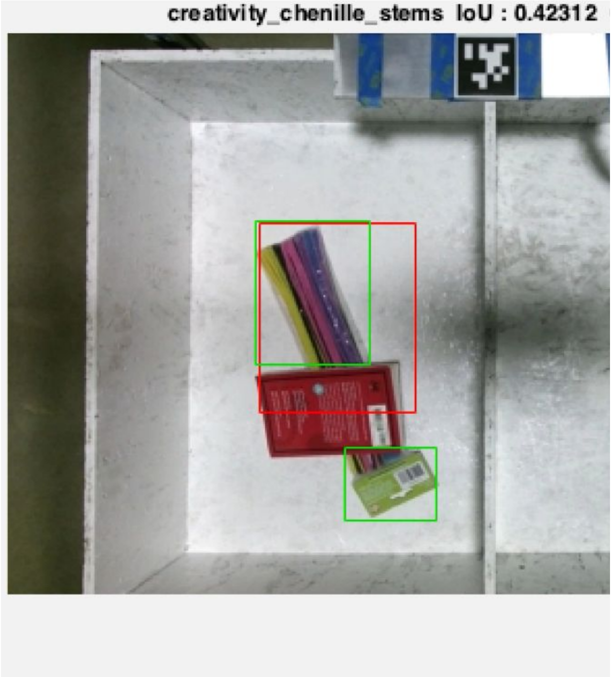
Faster R-CNN

FCN



Comparison Result: Occlusion

Faster R-CNN



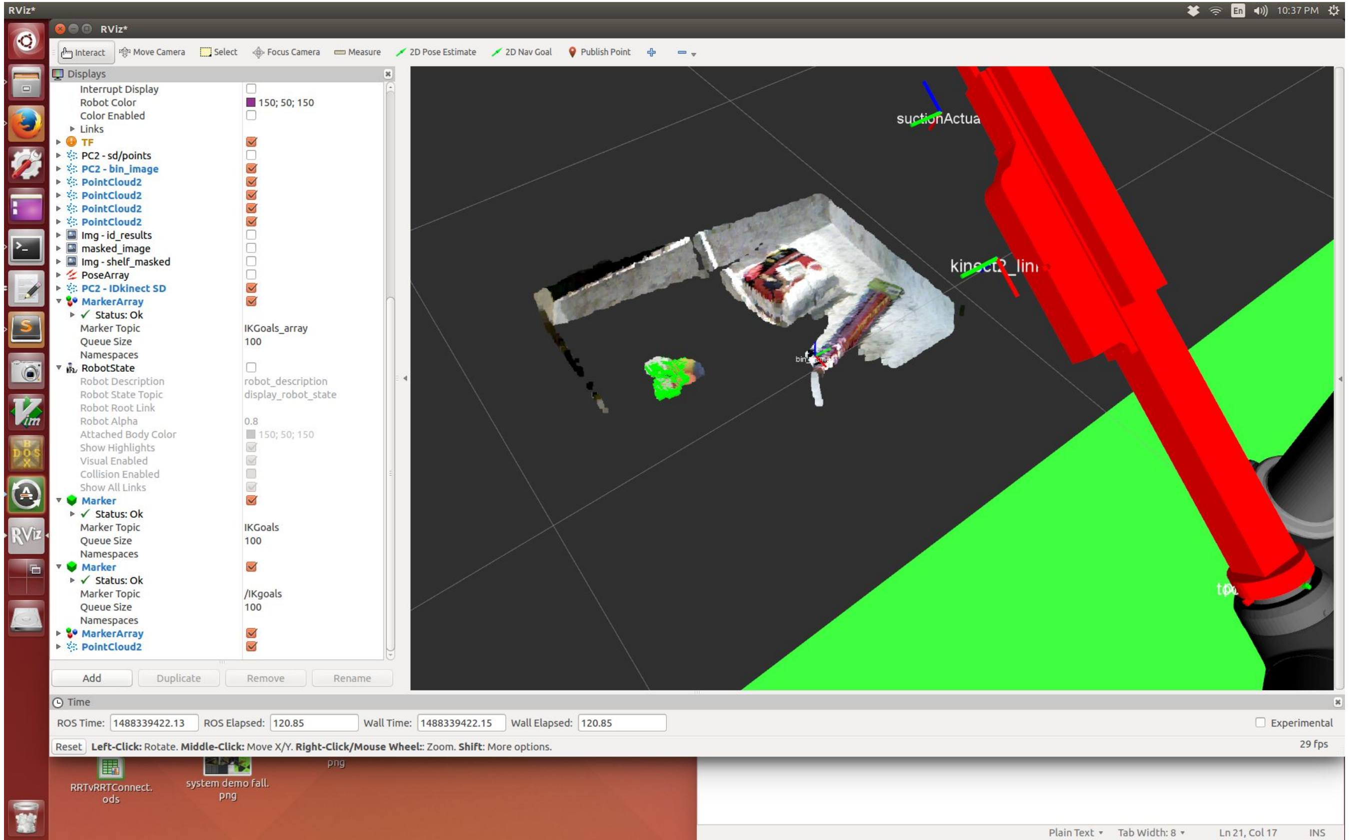
FCN

Comparison Conclusion

- Use FCN for object identification and point cloud segmentation
- Use Faster R-CNN for sanity check

	Drift/scale accuracy	Occluded data	False Positive	Bounding Box
Faster RCNN	Inaccurate	Fail	Less	Reliable
FCN	High IoU	Robust	More	Need filter

Vision Current Stage



Vision - Challenges

Sensors:

- Using more than one sensor per one system caused USB transmission error
- Inability to empirically evaluate sensors against one another due to firmware issues and time constraints. Pivoted to ASUS Xtion Pro based on SBPL lab experiences and form factor for the end effector.

Vision - Remaining Challenges

- Ensure FCN and Faster-RCNN robustness on new items
- Demonstrate an ability to identify unknown item classes
- Produce high quality point clouds from stitching
- Integrate PERCH

Grasping - Functional Description

Known Items:

- Use 1-DOF suction for 34 out of 40 challenge items
- Use electromagnets for 5 trouble items
- 1 item currently blacklisted (epsom salts)

Unknown Items (beyond MRSD course scope):

- Create a strategy for implementing suction on unknowns
- Attempt to implement two-finger grasping this summer, use Cornell Rectangular Representation research

Grasping - Functional Description Cont’d

Deformable Grasping using PCL:

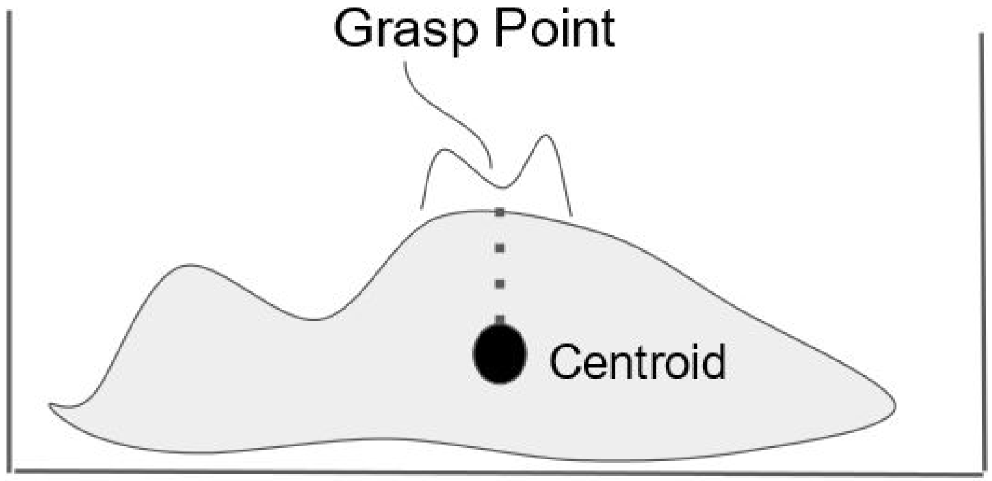
- Use for any deformable objects
- Use for any objects that testing demonstrates 6-DOF is unwarranted

6-DOF Grasping using PERCH:

- Use for items requiring specifically oriented grasps (such as the dumbbell)

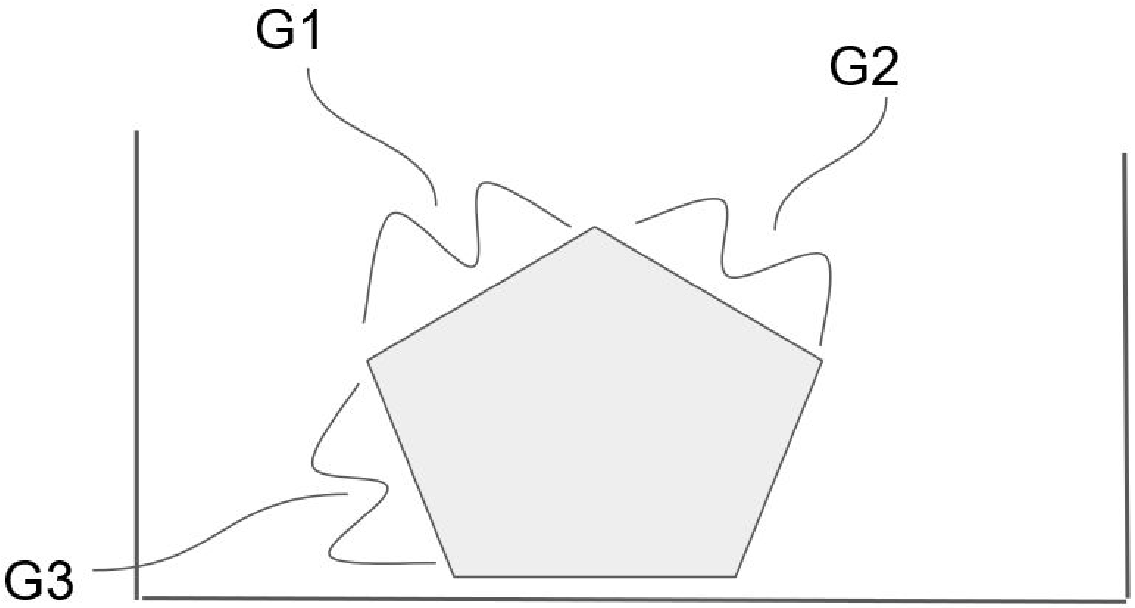
Grasping - Deformables Strategy

Generate many grasp points and rank them based off of weights such as item centroid, pass them to planning and implement the first valid pose.



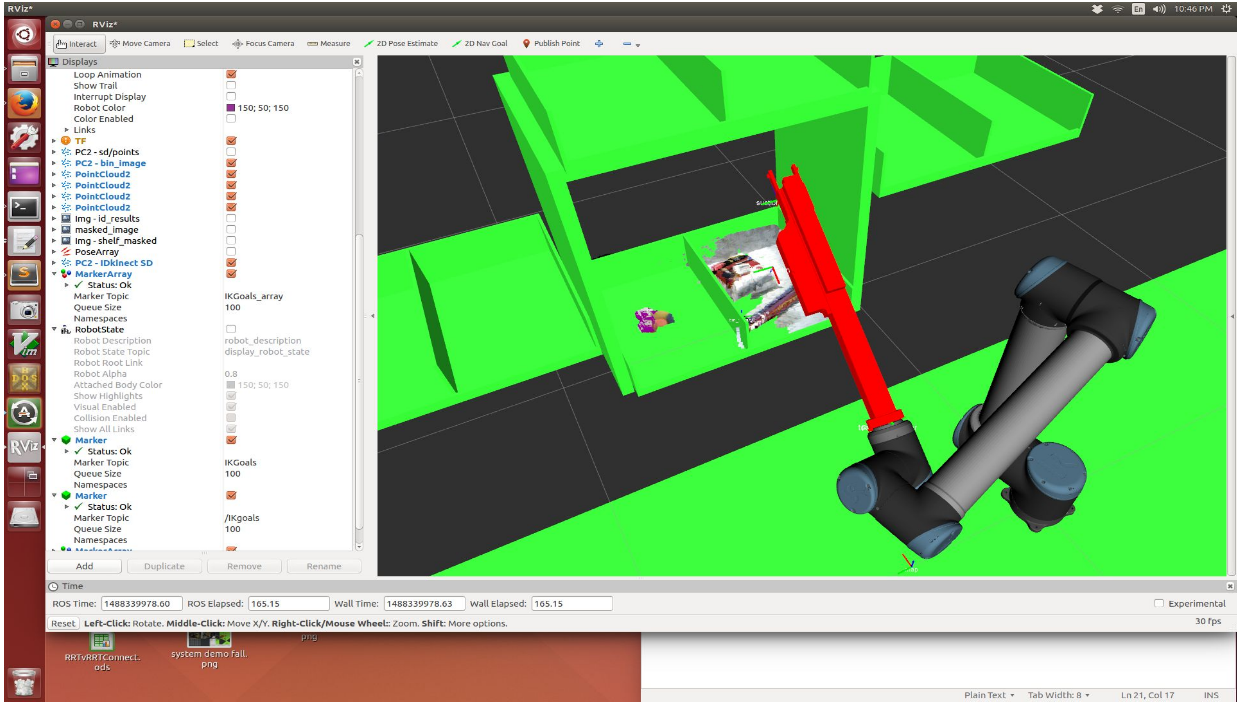
Grasping - Rigid Objects Strategy

Create predefined grasp points based on 3D models for rigid objects. Identify the model orientation in the planning scene and the pose location(s) accordingly.

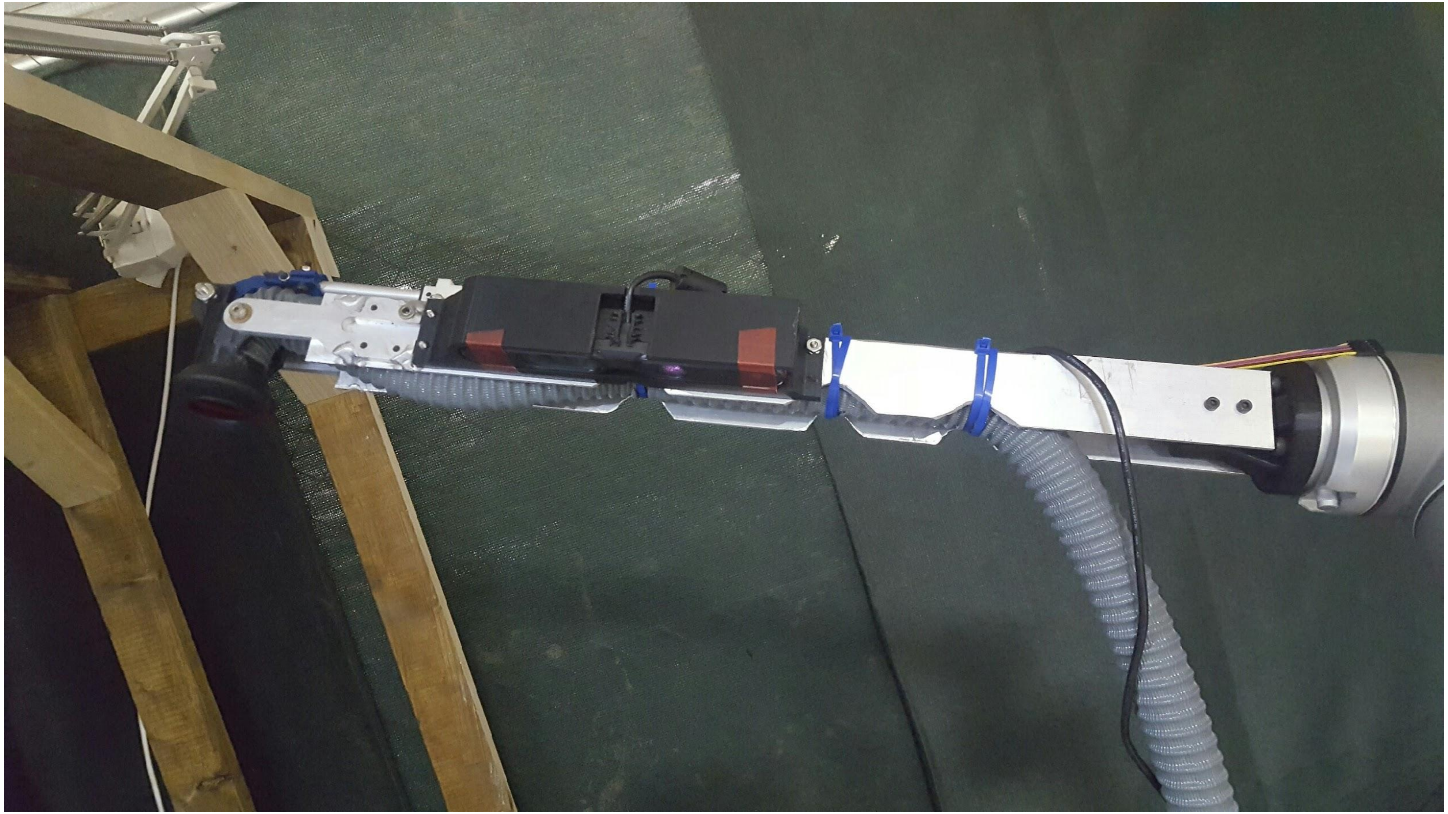


Grasping Current Stage - Software

- Deformable grasping poses (translation only) + FVE functionality such as vacuum feedback and control



Gripper - 1-DOF High-flow Vac and Electromagnets



Grasping - Challenges

- New contest items are more difficult than in previous years, resulting in a blacklisted item.

- Translation within grasp poses for deformables is currently implemented, but there is still an unresolved bug with pose quaternions which pushed back a system demonstration.

Grasping - Remaining Challenges

- Implement and integrate 6-DOF model grasping
- Verify electromagnet viability, install onto the end effector
- Pursue two-finger gripping for competition unknown items

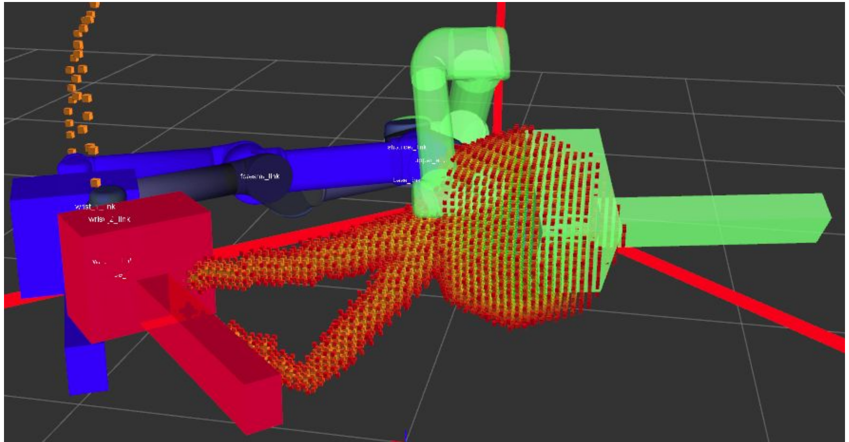
Planning - Functional Description

- Primary planner EGWA*
- Secondary planner RRT or RRT Connect
- 6-DOF, 7-DOF, and 8-DOF planning groups. Allows for isolation of arm, 1-DOF gripper, and base slider when performing different tasks.

Planning Current Stage

- 7 position control over the base slider, allows for slow state machine control (moving to 32 position and integration into SBPL for faster runtime).

- Strategies and system modeling parameters have been created for integration of the planning groups and 1-DOF into SBPL.



Planning - Challenges

- SBPL takes longer to reinstate after making system changes, and RRT planners cause unwanted actions often when integrating/testing.

- Slider feedback was tricky to debug, often reported false positives.

Planning - Remaining Challenges

- Create and implement control over all three planning groups
- Implement more robust slider control
- Integrate 1-DOF gripper control
- Generate prep poses and experience graph for all bins

Competition Strategy

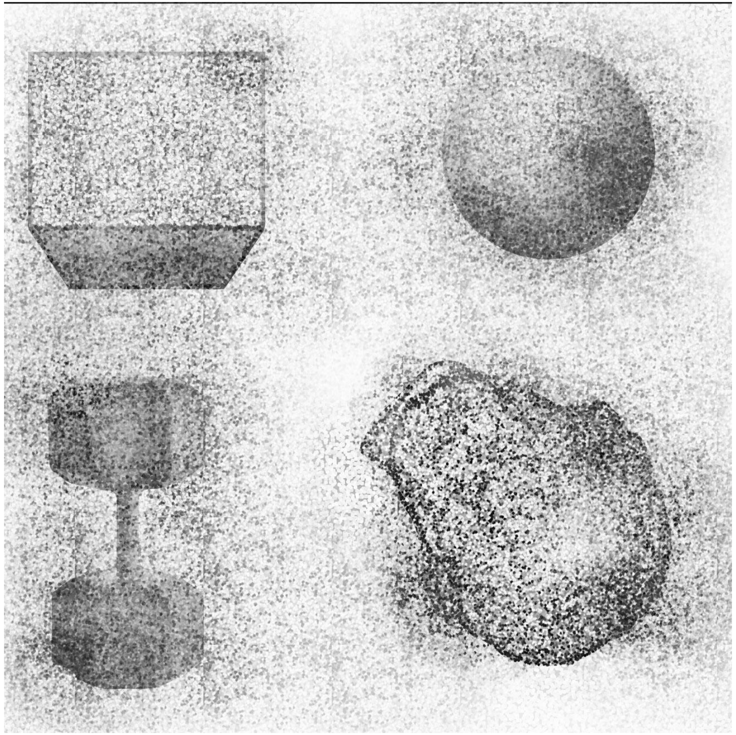
Picking:

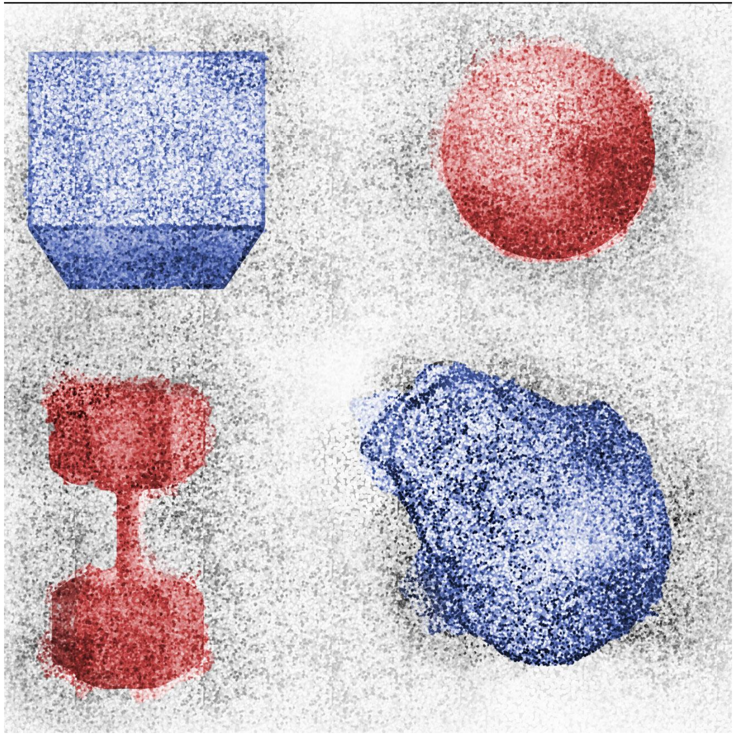
- Arrange item locations within bins so that no more than 2 unknowns are within a bin, of separable classes which are distinguishable by the depth image CNN.
- Identify items by RGB, then depth image and PERCH. Only one unidentified object should remain. It is then identified through the JSON by process of elimination.

Stowing:

- Store all unknown items in the same bin and report the same location (common strategy last year).

Picking Strategy - Example Layout





Project Management - Schedule Status

- Project is on track for MRSD course SVE. The scope of work remaining for the competition based off of the unknown item classes is still being determined.

- Point cloud stitching, and shelf and vacuum hardware procurement and installation are behind schedule by 1-2 weeks.

- Grasping code and gripper hardware, as well as high-level system/competition strategies, are ahead of schedule by 1-3 weeks.

Project Management - Catching Up

- Shelf and vacuum hardware and point cloud based tasks are current top priorities!

Spring Test Plan

PR#10 (March 22nd) - Demonstrate a picking run using all system bins and a small subset of items. Also show the ability to project 6-DOF grasping poses into the planning scene for 2 or more items.

PR#11 (April 5th) - Show the ability to interpret JSON orders and output a JSON file reporting item locations after a picking run. Also demonstrate tabletop control over all anticipated system actuators for SVE as well as the electromagnets.

PR#12 (April 17th) - Demonstrate a full competition-style picking run with the new shelf, gripper, and all actuators integrated.

Spring Validation Experiment

Picking Scenario for APC	
Date: 04/25/2017 **Location:** NSH Level B Fence/High Bay **Testing Area:** 3m x 2.5m working area	**Testing Equipment Needed:** ● 1-DOF Suction Gripper/Final Design Gripper ● 1 RGB-D Camera (ASUS Xtion Pro) ● UR10 w/ Linear Actuator ● Fabricated Shelf and Platform Framework ● 3 Totes ● 2 Workstations ● 32 APC 2017 Items

Spring Validation Experiment

Picking Scenario for APC

Test Process:

1. The shelf will be populated with 32 items from the APC 2017 dictionary.
2. The system will be given a JSON file reflecting the correct item bin locations, as well as the desired tote for each item.
3. The perception system will recognize items in each bin and report the results to the workstation.
4. The perception system will localize itself and the shelf to the robot arm platform.
5. The perception system will detect the item of interest determined by the workstation and recognize its pose to find a valid suction/gripping surface.
6. The path planner will move the UR10 outside the desired bin or over the desired item surface.
7. The grasping system will implement a strategy based on the item to attempt to grasp the item on a predefined surface, communicating with path planning to move the arm.
8. The suction system will adhere to the item surface.
9. The path planner will move the item over the desired tote.
10. The grasping system will disengage suction and drop the item into the tote.
11. Repeat steps 5-10 till time is up or all tasks are completed.

Spring Validation Experiment

Quantitative Goals
1. Pick up at least 12 items and drop them inside their target totes within 15 minutes, dropping no more than 2 items to the floor 2. Drop items into the totes from no more than .3m from the bottom of the totes 3. Generate an item report in the form of a JSON for the items remaining on the shelf, with 100% accuracy for item bin locations (excluding any dropped items)

SVE Example Environment

Budget

Starting Budget		$5,000.00
Linear Actuator	$2,622.19	
Server Rack	$769.99	
RealSense Kits	$298.00	
Arm Stand	$727.96	
Total Spent	$4,418.96	
Remaining Funds		**$581.04**

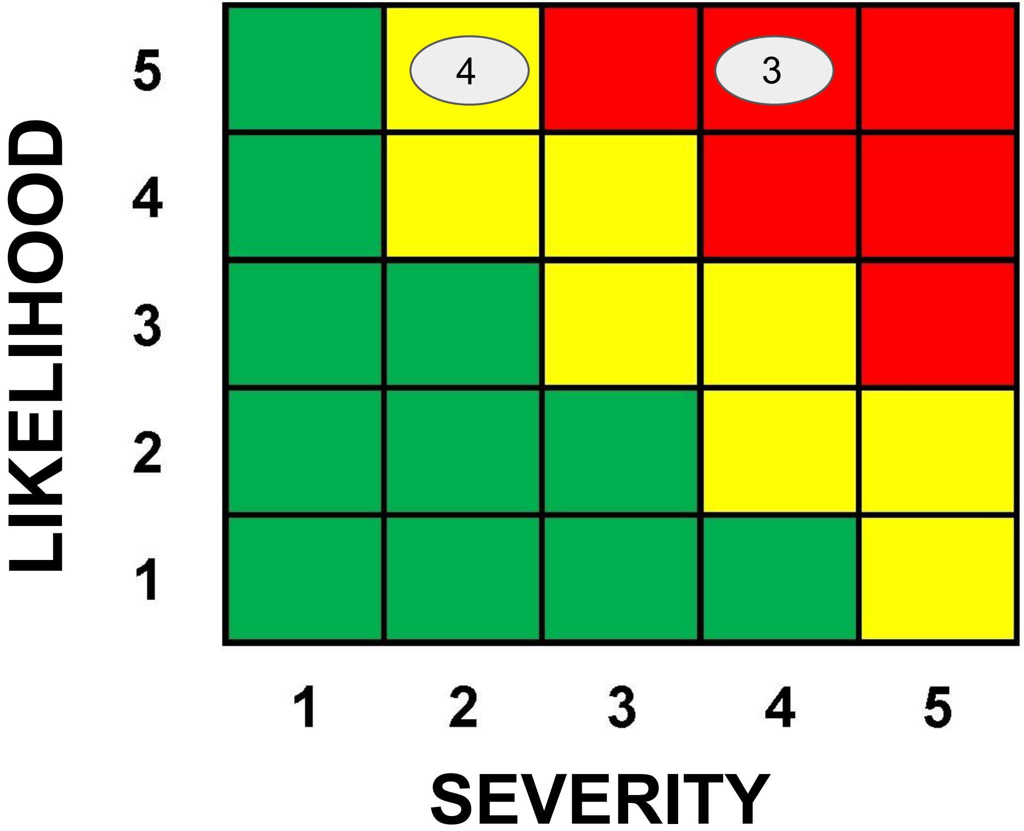
Expected Future Expenses (Estimates)		
Frame Actuation Hardware		$1,000
Structural Aluminum		$2,000
Vacuum		$0-$3000
Gripper		$0-$1000
Lighting		$100
Total Anticipated Cost		**$3,100-$7,100**

Budget - Contingencies

- We would like to use the remainder of our MRSD course budget (~$500) for spare parts and time-sensitive acquisitions of other small parts, cables, etc (this will be a negotiation with SBPL).

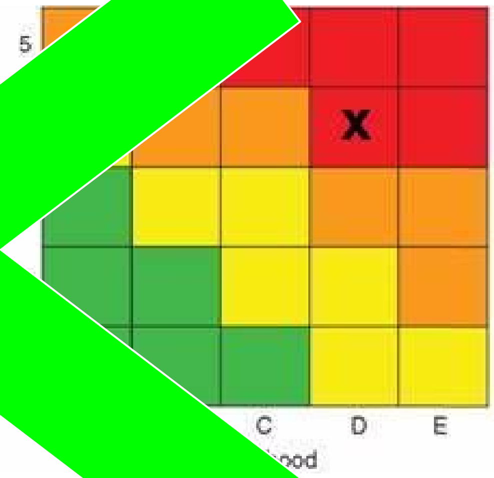
- Obtaining spare parts for big ticket items such as the UR10 and slider is unfortunately infeasible due to high cost.

Risk Management



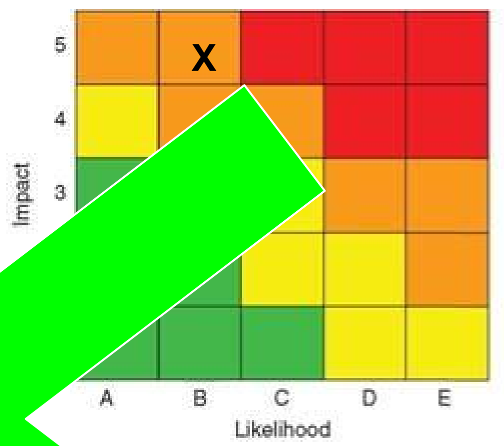
Risk Analysis: Major Risk 1

Risk Title	Risk Owner	Date Submitted	Date Updated
Not enough time to pivot gripper design	Michael	[illegible]16	-
Risk Description		[illegible]Type	
APC 2017 items are significantly different requiring novel gripper design and testing not realizable in time window		*Techni*[illegible]	[illegible]
Consequence		*Schedule*	[illegible]
Use default gripper for Project, APC **Blacklisted Items**		*Cost*	[illegible]
		Proje[illegible]	[illegible]
Risk Reduction Plan	**Timeline**	**Ex**[illegible]**utcomes**	
1. Design and Prototype/Purchase Alternate Grippers for all reasonable item eventualities	9/1/2016 -2/1/2017	[illegible]pedite pivot	
2. 1-DOF gripper designed and fabricated (best guess)	9/1/2016 -12/1/2016	Fewer items pickable but competition ready	
3. 1-DOF gripper tested on items(default)	2/1/2016-APC		



Risk 2 - Generic Items/MSCV Students

Risk Title	Risk Owner	Date Submitte d	Date Updated
Generic Item List	Perception team		-
Risk Description		ype	
Scope of generic items too large to implement		*Technic*	
Consequence		*Schedule*	
Not competitive in APC 2017		*Cost*	
		Project	
Risk Reduction Plan	**Timeline**	**Ex utcomes**	
1. Integrate PERCH with perception	12/1/2016	non-deformables	
2. Get MSCV team on board	12/15/2017-APC	Generic item classifier	

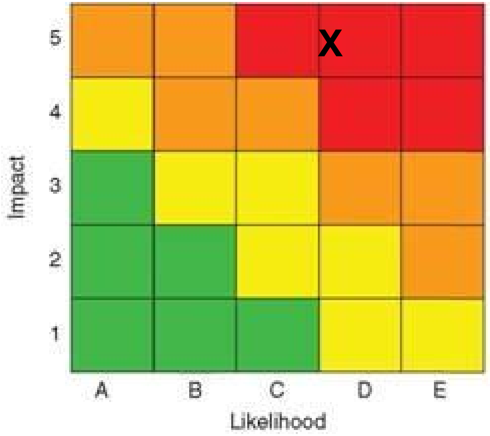


Risk 3 - System Cost Over Budget

Risk Title	Risk Owner	Date Submitted	Date Updated
System Cost Over MRSD Budget	Akshay Bhagat	11/16/2016	-

Risk Description	Risk Type	
System cost to be competitive in APC requires custom shelf design and more expensive vacuum system	***Technical***	x
Consequence	***Schedule***	x
Not competitive in APC 2017	***Cost***	
	Project	x

Risk Reduction Plan	Timeline	Expected Outcomes
1. Secure funding from SBPL	12/01/2016-07/31/17	System remains within budget
2. Cut Cost: Make passive shelf system	12/15/2016-APC	System will meet base requirements but not be competitive for APC



Risk 4 - PERCH

<table>
<tr><th>Risk Title</th><th>Risk Owner</th><th>Date Submitted</th><th>Date Updated</th></tr>
<tr><td>Generic Item List</td><td>Perception team</td><td>11/16/2016</td><td>-</td></tr>
<tr><th colspan="2">Risk Description</th><th colspan="2">Risk Type</th></tr>
<tr><td colspan="2">PERCH is being modified by the SBPL lab to fit the needs of this competition. This may not be accomplished in time.</td><td>Technical</td><td>x</td></tr>
<tr><th colspan="2">Consequence</th><td>Schedule</td><td>x</td></tr>
<tr><td colspan="2" rowspan="2">Heavy reliance on depth image CNN for unknown items</td><td>Cost</td><td></td></tr>
<tr><td>Project</td><td>x</td></tr>
<tr><th>Risk Reduction Plan</th><th>Timeline</th><th colspan="2">Expected Outcomes</th></tr>
<tr><td>1. Integrate PERCH with perception</td><td>05/01/2017</td><td colspan="2">Identify non-deformable unknown items</td></tr>
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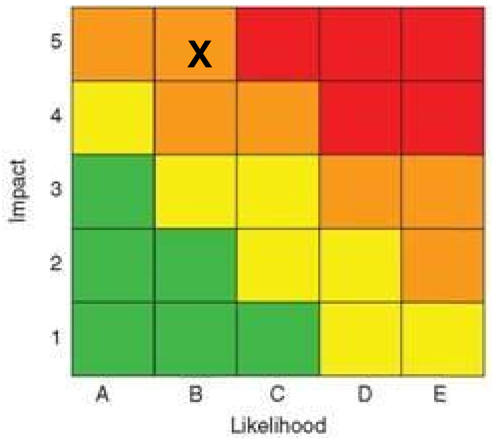
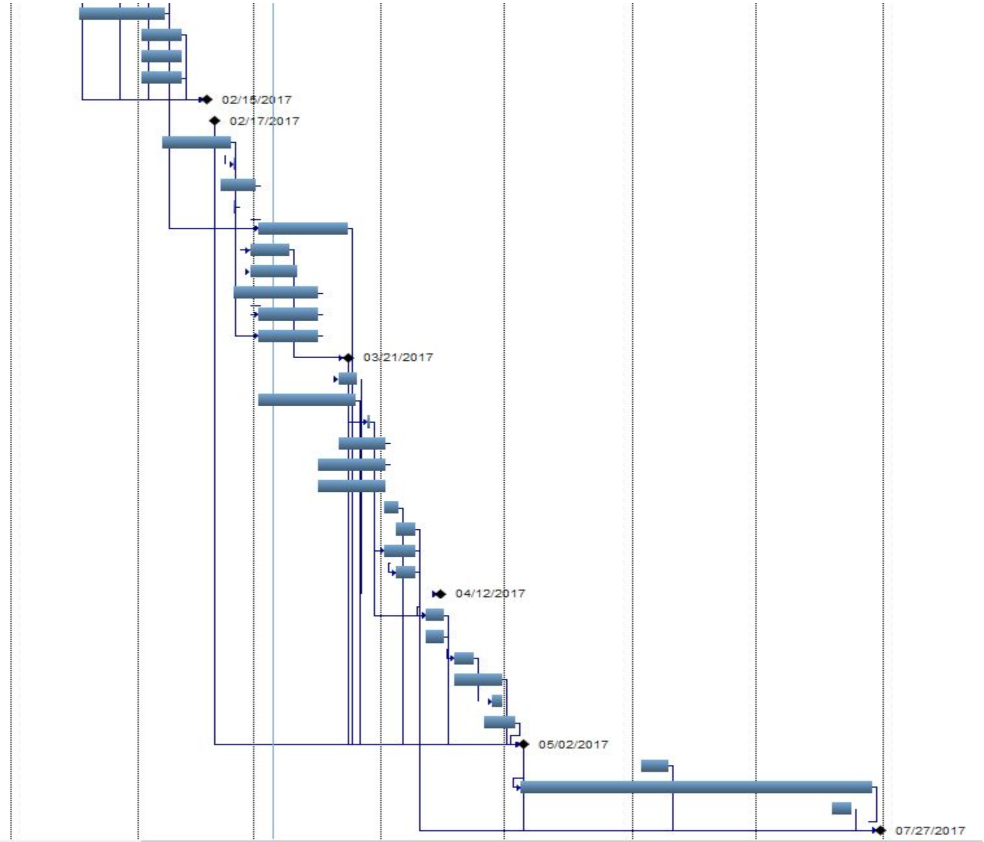


The End

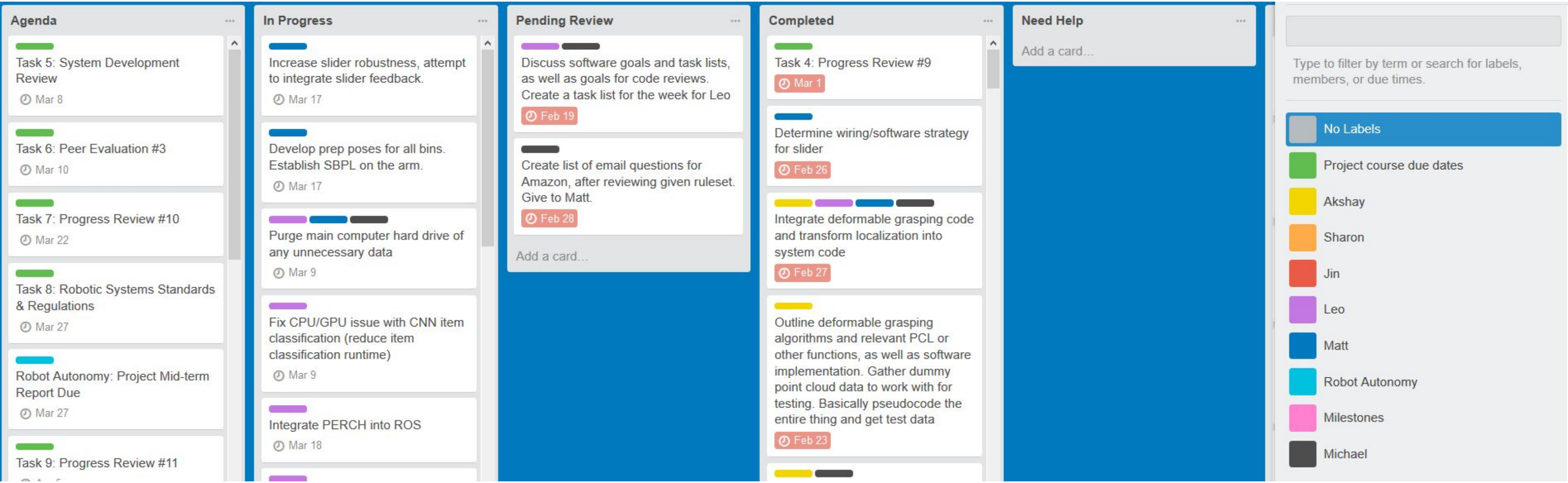
Thank you :)

Gantter slide (for potential Dimi question)

Faster-RCNN Implemented	3w?	01/17/2017	02/06/2017	
Implement Linear Actuator Controls	8d?	02/01/2017	02/10/2017	
Implement Bin Point Cloud Segmentation	8d?	02/01/2017	02/10/2017	
Integrate 4 Kinects into Vision System	8d?	02/01/2017	02/10/2017	
System Mockup (w/out actuated drawers)	3d?	02/13/2017	02/15/2017	1,2,3,4,5,6,8,9,
Determine Strategy for "Unknown" Items	1d?	02/17/2017	02/17/2017	
Gripper Design Finalized	13d?	02/06/2017	02/22/2017	
Purchase System Vacuum	1d?	02/23/2017	02/23/2017	14
Kinect Fusion Implemented	1.4w	02/20/2017	02/28/2017	
Purchase Shelf Actuators and Rails	1d?	02/23/2017	02/23/2017	
Select Final RGB CNN	16d	03/01/2017	03/22/2017	7,8,16
Procure Shelf Actuators and Rails	8d?	02/27/2017	03/08/2017	17
Procure System Vacuum	10d?	02/27/2017	03/10/2017	15
Deformables Grasping Code Implemented	3w?	02/23/2017	03/15/2017	
Integrate PERCH	11d?	03/01/2017	03/15/2017	16
Gripper Fabricated	11d?	03/01/2017	03/15/2017	14
Run System w/ All Actuated Hardware Implemented	8d?	03/10/2017	03/21/2017	19
Integrate Final Gripper	5d?	03/20/2017	03/24/2017	20,23
Determine Strategy for Picking Portion (w/ unknowns)	18d?	03/01/2017	03/24/2017	
Purchase Structural Aluminum	1d?	03/27/2017	03/27/2017	24
Draft Final Drawer Design w/ April Tags	10d?	03/20/2017	03/31/2017	
Implement Grasping Surfaces for New Rigid Items into Syster	13d?	03/15/2017	03/31/2017	
Determine Strategy for Stowing Portion (w/ unknowns)	13d?	03/15/2017	03/31/2017	
Determine Bin Placement	2d?	03/31/2017	04/03/2017	
Determine Summer Team Logistics	5d?	04/03/2017	04/07/2017	
Procure Structural Aluminum	6d?	03/31/2017	04/07/2017	27
Fabricate Final Drawer Design w/ April Tags	5d?	04/03/2017	04/07/2017	28
Meet SVE Requirements	1d?	04/12/2017	04/12/2017	21,25,26,29,31
Build Shelf and Frame (including actuator, sensor, and rail m	5d?	04/10/2017	04/14/2017	27,33,34
Purchase Lighting Materials	5d?	04/10/2017	04/14/2017	
Procure Lighting Materials	5d?	04/17/2017	04/21/2017	37
Determine Strategy for Pick and Stow	10d?	04/17/2017	04/28/2017	
Install System Lighting	3d?	04/26/2017	04/28/2017	38
Finalize System Architecture	6d?	04/24/2017	05/01/2017	
MVP for All Challenge Requirements	1d?	05/02/2017	05/02/2017	13,18,22,24,26
Determine Travel Logisticis (including shipping)	5d?	06/01/2017	06/07/2017	
Testing/Finetuning/Troulbeshooting	61d?	05/03/2017	07/26/2017	42
Become Efficient at System Disassembly and Reassembly	5d?	07/17/2017	07/21/2017	
Compete at Amazon Picking Challenge	1d?	07/27/2017	07/27/2017	32,42,43,44,45



Trello slide (for potential questions)



Item List (for potential questions)