Evaluating End-Effectors and System Integration for Warehouse Picking

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Presented by Zakary Littlefield
Introduction

The Problem
• Cluttered and small workspace
• Poor visibility
• Objects vary widely based on size, shape, surface texture and weight

Solution
• Multiple end-effectors, good at picking various items
Hardware Setup

- Dual-arm Yaskawa Motoman SDA10F Robot 7-DoF per Arm + 1 DoF for Torso
- 2 different end-effectors on each hand
- Kiva Systems shelf as used in the Amazon Picking Challenge
- RealSense 3D camera
- Vacuum Sources
Hardware Setup – RightHand Robotics ReFlex Hand

**Pros:**
- Rubber fingers provide good friction
- Strong servo motors for heavy items (<5lb)
- Ability to execute caging grasps
- Built in pressure sensors allow for easy grasp validation

**Cons:**
- Even though compact relative to other similar hands, it is still large
- Hard to plan for
## Hardware Setup – Vacuum Sources

<table>
<thead>
<tr>
<th>High Vacuum (&lt; -95kPa), Low Flow</th>
<th>Low Vacuum (~-12kPa), High Flow</th>
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</thead>
<tbody>
<tr>
<td><strong>Pros:</strong></td>
<td><strong>Pros:</strong></td>
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<tr>
<td>• High vacuum strong suction/lifting force, great for heavy objects (good seal and no leaks assumed, i.e. smooth continuous surfaces)</td>
<td>• Inexpensive vacuum source (e.g., vacuum cleaner)</td>
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<tr>
<td>• Allows for smaller suction cups (good in tight spaces)</td>
<td>• Good tolerance to vacuum leaks</td>
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<tr>
<td>• Works on uneven surfaces as well as porous materials (e.g., fabrics)</td>
<td>• Precise positioning not as important (easier planning)</td>
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<tr>
<td>• Weaker suction/lifting force, can be problematic for heavy objects</td>
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<tr>
<td>• Requires larger vacuum opening (e.g. suction cup) to accommodate the high air flow;</td>
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<tr>
<td><strong>Cons:</strong></td>
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<tr>
<td>• Expensive (air ejectors, air compressor, etc)</td>
<td>• Weak suction/lifting force, can be problematic for heavy objects</td>
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<tr>
<td>• Even small leaks can affect grasp robustness</td>
<td>• Requires precise placement if smooth surfaces are limited</td>
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<tr>
<td>• Not good for uneven surfaces</td>
<td>• Will not work on porous materials</td>
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</tbody>
</table>

*Air Compressor Feeding Air Ejector*  
*6hp Dry/ Wet Shop Vac*
Hardware Setup – High Vacuum/Low Flow – Custom End-Effector by Unigripper

Pros:
• Wrist-like DoF allows approaching object from the front and from the top
• Maintains grasp even if a large number of the openings are unconcluded by the object (vacuum leak)

Cons:
• The presence of vacuum foam and the low flow of UniGripper’s vacuum technology required the gripper to be pressed against the object in order to attach itself. Objects grasped from the front can easily topple over
Hardware Setup – High Vacuum/Low Flow – Custom End-Effector by Unigripper (Modified)

Pros:
- DoF allows approaching object from the front and from the top
- 2 suction cups vs array of openings greatly increases the suction force produced (objects attach to end-effector much easier)
- More compact compared to UniGripper’s vacuum solution

Cons:
- More accurate planning is required as good seal is needed at Both suction cups. Leaving one open is a very large vacuum leak.
Hardware Setup – Low Vacuum/High Flow – Custom End-Effector Designed and Built In-House

Pros:
- Much higher air flow can tolerate very large leaks and works with uneven and porous objects, requiring less precise planning
- Asymmetric cup provides secure horizontal grasps while keeping overall cup diameter small
- DoF allows approaching object from the front and from the top

Cons:
- High flow requires a thick hose and large suction cup, which limits the minimum size of gripper achievable
Hardware Setup – Low Vacuum/High Flow – Unigripper Hybrid Gripper

Pros:
• Suction cup at the tip allows reaching in tight spaces and attaching to lighter objects securely
• UniGripper planar surface allows grasping flat objects
• Relatively thin Parallel fingers allow for reaching deep inside bin.
• Strong parallel motors allow grasping of heavy objects

Cons:
• Large size due to UniGripper vacuum technology, long fingers and need to pick heavy objects (large motors required)
System Integration – Software Architecture
System Integration – Perception

- PRACSYS group proposed a perception solution using Regions with Convolutional Neural Network (R-CNN)
- A dataset of RGB-D images of all the APC objects is available in [http://pracsylab.org/rutgers_apc_rgbd_dataset](http://pracsylab.org/rutgers_apc_rgbd_dataset)
- In order to estimate the pose of an object
  - Move the camera to 4 predefined positions
  - Process the RGB-D information from those positions
  - Apply physics to correct the estimate
System Integration – Motion Planning Pipeline

- Initial Object Pose
- Retraction State
- Connection State
- Velocity Kinematics
- Local Planning
- PRM* Roadmap
- Initial State
- Target Object Pose
System Integration – Grasp Planning

• **Create online a set of *feasible* grasps**
  – Use the end-effector geometry and move it on the graspable surfaces of the object
  – Reject the grasps with insufficient overlap between the end effector and the object surface

• **Create a *valid* set of grasps**
  – Get an IK solution for each grasp in the feasible set
  – Accept all the collision free grasps

• **Invoke motion planning to provide a plan that moves the end-effector in one of the valid grasps**
Experimental Results – Unigripper Vacuum End-Effector vs ReFlex Underactuated Hand
Conclusions & Future Work

• Dual-arm manipulator is beneficial
• Vacuum end-effectors are compact and very promising
• More work needed on perception and planning
• High-flow vacuum end-effector currently under evaluation
• Hybrid gripper end-effector currently under evaluation
• Currently developing soft-robotics elastomer-based end-effectors to minimize hardware failures and encourage use of machine learning