Amazon Picking Challenge 2016: Team NimbRo of University of Bonn

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Computer Science Institute VI - Autonomous Intelligent Systems
Outline

System

Control

Perception

Special Features
System Overview

UR 10 Arm (6 DOF)

Air velocity sensor

2x Intel RealSense SR-300 + LED light

Linear actuator

Foldable suction finger

Total: 6 + 2 DOF

Suction strength control

Central vacuum cleaner (3100 W)
Concept and Design

- UR 10: Workspace, Payload, Cost, Safety
- Single suction gripper: Avoid design complexity
  - Second supporting finger planned
- Folding finger:
  front, top, and side grasps

Aim for highest performance at lowest complexity!
Outline

- System
- Control
- Perception
- Special Features
Motion Generation

- Replace complex motion planning with:
  - Keyframe-based motion generation
  - Collision detection at runtime (triggered in picking run)

- Assumption: If we can see a point, we can suction it

- Self-collision detection using MoveIt!

- Avoid collisions with shelf in IK solver!
Inverse Kinematics

- Redundancy resolution by **null-space cost optimization**:
  1. Joint limit avoidance
  2. Cartesian plane avoidance (keep wrist out of shelf/tote)
  3. Keep linear extension short
- Robust solution using **damped least squares**
- For in-shelf manipulation, only position + suction direction (5D IK)
Outline

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Special Features
Sensors

2x Intel RealSense SR-300

3 Depth measurements per pixel

1) Depth 1
2) Depth 2
3) RGB Stereo

Fusion: 2 out of 3
RGB

Depth
Data Acquisition

• ca. 100 images per setting (shelf/tote)
  - → 10 images per object

• Manual annotation
Deep Features and Online Learning

[Johnson et al., CVPR 2016]

DenseCap
Deep Features and Online Learning

DenseCap

[Johnson et al., CVPR 2016]

a plate of food, food on a plate, a blue cup on a table, a plate of food, a blue bowl with red sauce, a bowl of soup, a cup of coffee, a bowl of chocolate, a glass of water, a plate of food, a silver metal container, a small bowl of sauce, table with food on it, a slice of orange, a table with food on it, a slice of meat, yellow and white cheese.
Deep Features and Online Learning

[Johnson et al., CVPR 2016]

DenseCap

Replace Text Generation with Online SVM Training
Deep Features and Online Learning

Gloves
Glue sticks
Sippy cup
Semantic Segmentation

[Husain et al., RA-L 2016]

Fully Convolutional Neural Network
- Pre-trained OverFeat on ImageNet
- Fine-tuned (last 3 layers) on APC Data

Training:
- ~ 3 hours on multiple GPUs

Testing:
- ~ 200 ms per image
Semantic Segmentation

RGB

HHA

Result
Combined Detection and Segmentation

[Image of a tray with various objects, and a diagram showing detection and segmentation results with different colors and overlays.]
Generic Grasp Pose Selection

- Center grasp for “standing” objects:
  - Find support area for suction close to bounding box center

- Top grasp for “lying” objects:
  - Find support area for suction close to horizontal bounding box center

- Custom rules for specific objects
  (9 rules in total)
6D Pose Estimation

- Capture item on turn table
- Build 3D model
- Generate proposals
- Register to test image

V4R Library [Aldoma et al., ICRA 2013]
Pick / Stow Strategy

- **Pick:**
  - order A … L
  - On failure, retry at end
  - Drop at 3 predefined positions in tote

- **Stow:**
  - Try to put all items into one 20 points bin
    - (select the one with most free space)
  - Stow “large” items into own bin
    - (coffee, socks, paper towels, tissue box, curtain, pencil cup, mailer)
  - If leftover object at end, retry segmentation with all classes
Outline

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Perception

Special Features
Foldable Funnel
Foldable Funnel
Tricky Items to Grasp

- Heavy / cylindrical
  - Ensure that grasp is on **center of mass**!

- Hard to suck
  - Grasp on one ball
Sucking the Pencil Cup

1. Knock over

2. Suck on bottom
Sucking the Pencil Cup

1.5x
Summary

Stow: 2\textsuperscript{nd} place

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<th>Score</th>
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Pick: 3\textsuperscript{rd} place

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<td>NimbRo</td>
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</tbody>
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Do it as simple as possible, but not simpler!
Thank you

Max Schwarz  Sebastian Schüller  Christian Lenz  Arul Selvam Periyasamy
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