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Robotic assembly with bimanual and collaborative robots under uncertainty

Yiannis Karayiannidis, Phd, Docent

Assistant Prof., Mechatronics, SysCon, E2, Chalmers

Senior Researcher, RPL, CSC, KTH

yiannis@chalmers.se

www.yiannis.info

SARAFun project

www.sarafun.eu

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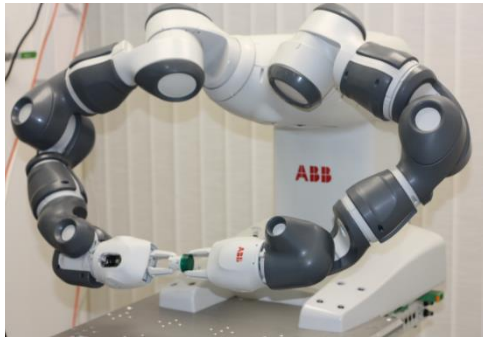
- Enable a non-expert user to integrate a new bi-manual assembly task on a robot in less than a day.
- Teaching an industrial robot an assembly task with minimum knowledge and effort required from the user.
- Sensory and control abilities required to plan and execute an assembly task.



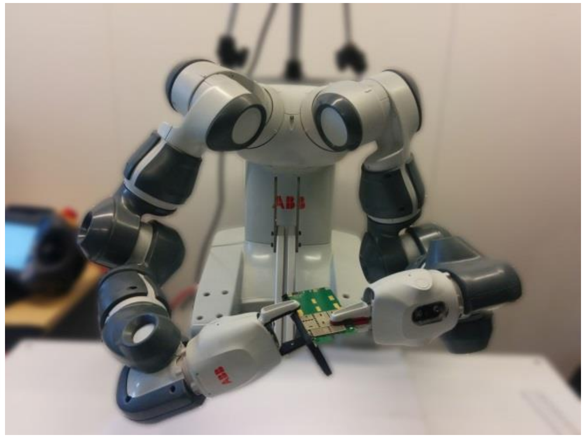


ABB Sweden

TECNALIA

Royal Institute of technology

Lund University

Centre for Research and Technology Hellas

Bielefeld University

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An overview of the SARAFun solutions

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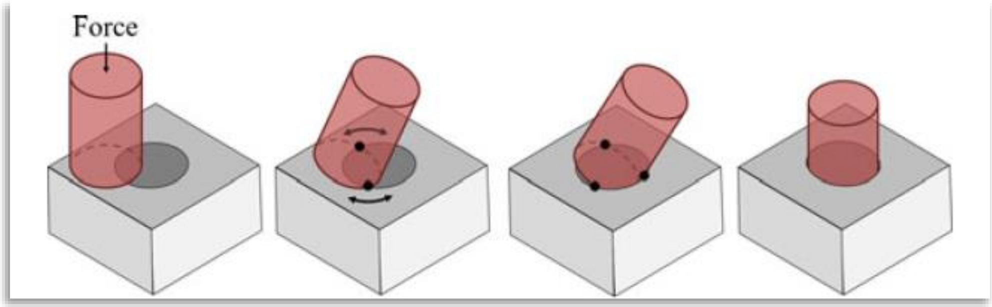
Small parts assembly

- Peg-in-hole insertion
- Threated fastener insertion (Screwing)
- Bolt and nut
- Snap-fit
- Insertion via deformation
- Folding



H. Park et. al, Transactions of Industrial Electronics 2017, VOL. 64, NO. 8

E.J. Nicolson & R.S. Fearing, ICRA93

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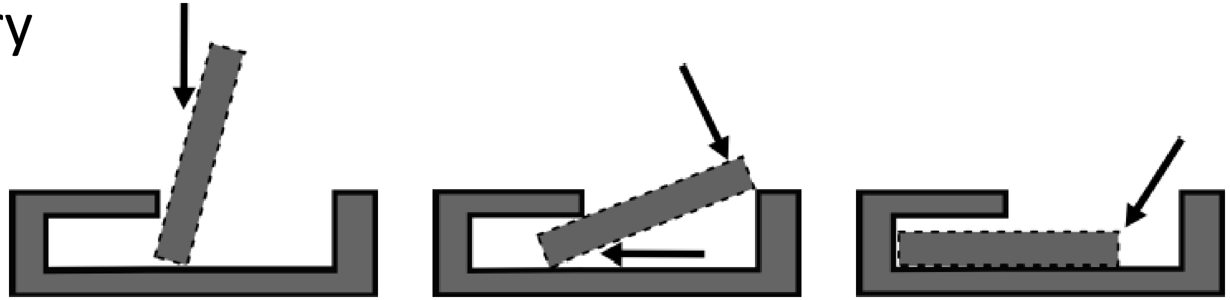
Folding assembly

- SARAFun scenarios

- Illustration of battery insertion



D. Almeida och Y. Karayiannidis, "Folding Assembly by Means of Dual-Arm Robotic Manipulation,“, 2016 IEEE International Conference on Robotics and Automation (ICRA), 2016, s. 3987-3993

D. Almeida, F. E. Viña och Y. Karayiannidis, "Bimanual Folding Assembly : Switched Control and Contact Point Estimation,“, IEEE-RAS 16th International Conference on Humanoid Robots (Humanoids), Cancun, 2016

Bimanual robots for assembly

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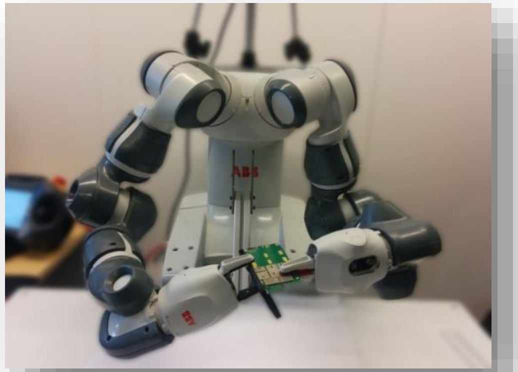
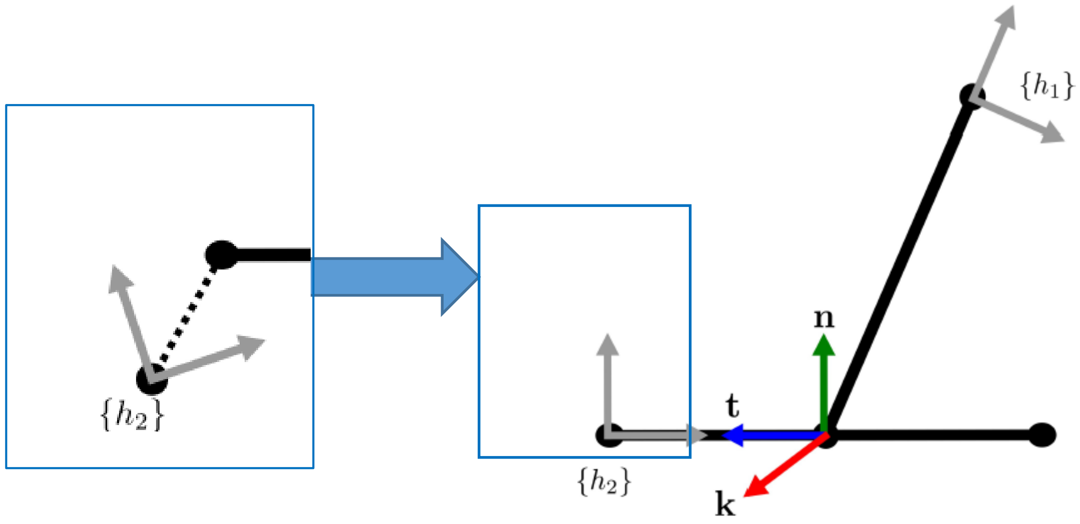
- Reduce the requirements for redesigning the workspace
- No fixtures are required for two parts assembly
- Strenth – Parrarel mechanical design
- Dexter
- Redundancy → *Manipulability* / *Sensors*

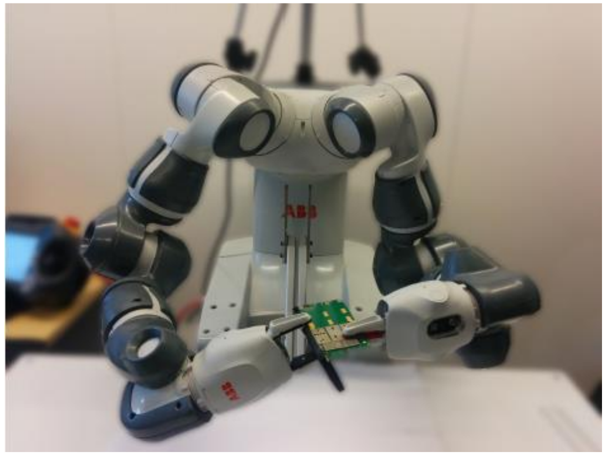


YuMi, RPL, KTH, Stockholm

Baxter, Amazon Picking Challenge, RPL team

Uncertainties in folding assembly





- **Uncertainties:**
  - Grasp pose
  - Contact point

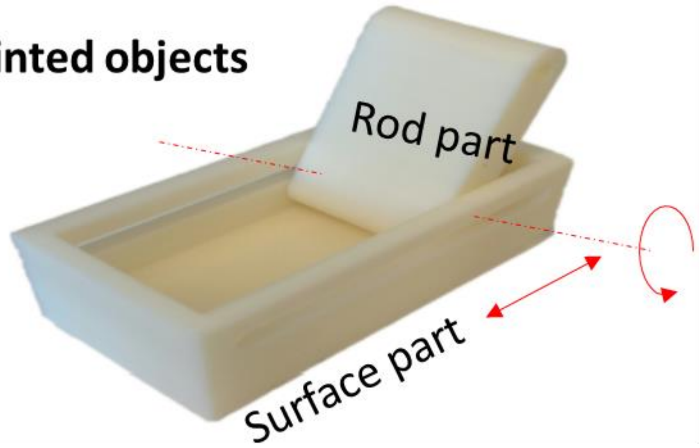
D. Almeida och Y. Karayiannidis, "Folding Assembly by Means of Dual-Arm Robotic Manipulation," in 2016 IEEE International Conference on Robotics and Automation, 2016, pp. 3987-3993.

- **Bimanual Robots:**
  - Flexibility – Redundancy
  - Allows for better exploitation of proprioception force/torque based perception

A 2 DOF mechanism kinematic model

- Pliers, scissors, drawers, etc. are mechanisms
- Assembly tasks can be modelled as mechanisms

3-d printed objects



"Sliding" velocity

Kinematics

$$\boldsymbol{v}_s = -\mathbf{r}_1 \times \boldsymbol{\omega}_1 + \mathbf{r}_2 \times \boldsymbol{\omega}_2 + \dot{\mathbf{p}}_1 - \dot{\mathbf{p}}_2$$
$$\boldsymbol{\omega}_r = \boldsymbol{\omega}_2 - \boldsymbol{\omega}_1$$

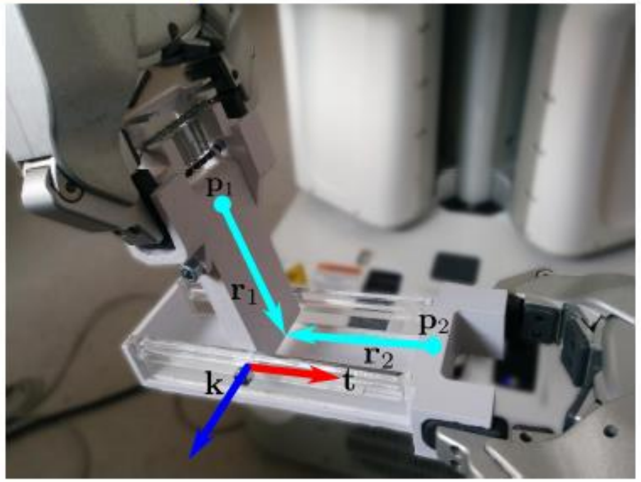
Relative angular velocity

Velocity constraints

Statics

$$\begin{cases} (\mathbf{I}_3 - \mathbf{t}\mathbf{t}^\top)\boldsymbol{v}_s = \mathbf{0} \\ (\mathbf{I}_3 - \mathbf{k}\mathbf{k}^\top)\boldsymbol{\omega}_r = \mathbf{0} \end{cases}$$
$$\boldsymbol{\tau}_i = \mathbf{r}_i \times \mathbf{f}_i$$

Force torque relationship



Dual Arm Formulation

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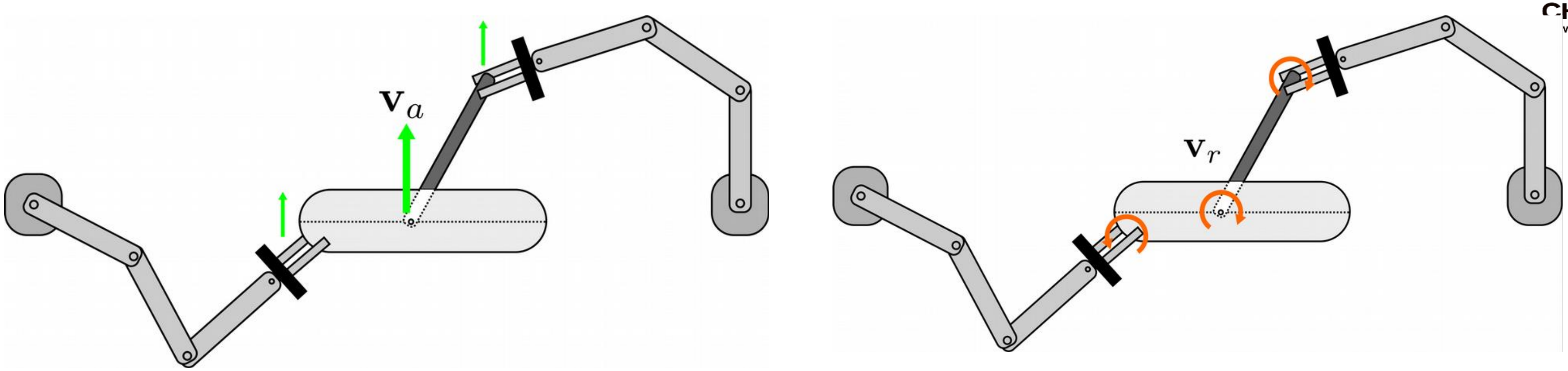


H. A. Park and C. S. G. Lee. ECTS, IROS 2016.

D. Almeida och Y. Karayiannidis, "Cooperative Manipulation and Identification of a 2-DOF Articulated Object by a Dual-Arm Robot," in 2018 IEEE International Conference on Robotics and Automation

Absolute motion twist

Linking

$$\mathbf{v}_E = \begin{bmatrix} \mathbf{v}_a \\ \mathbf{v}_r \end{bmatrix} \in \mathbb{R}^{12} \rightarrow \mathbf{v}_E = \mathbf{L}(\alpha)\mathbf{W}\begin{bmatrix} \mathbf{v}_1 \\ \mathbf{v}_2 \end{bmatrix} \rightarrow \mathbf{v}_E = \mathbf{J}_E\dot{\mathbf{q}}$$

Convert to grasp

Optimizing directly secondary objectives

Task-related

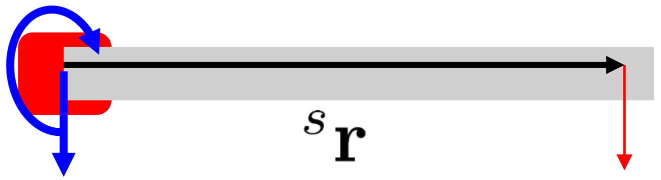
Determines the task-load for each end-effector

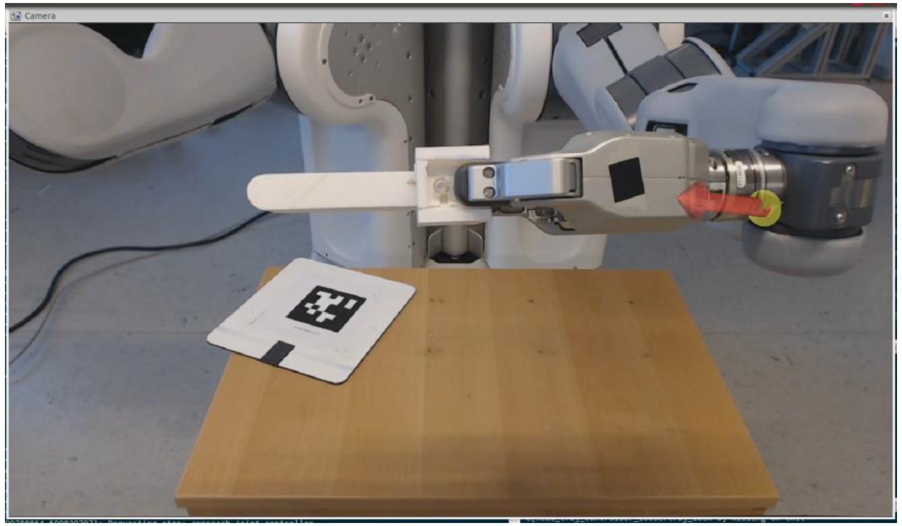
Extreme case: Master-slave

Kinesthetic perception: Force/torque

- Varignon's theorem (principle of moments -- mechanics)

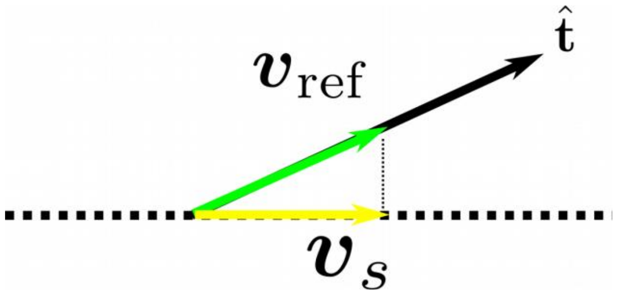
$$^{s}\boldsymbol{\tau} = {}^{s}\mathbf{r} \times {}^{s}\mathbf{f}$$

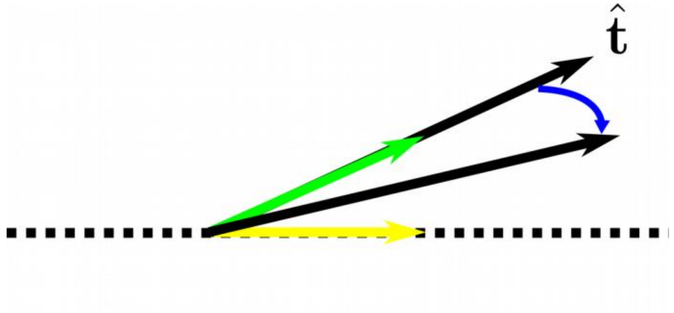




Kinesthetic Perception

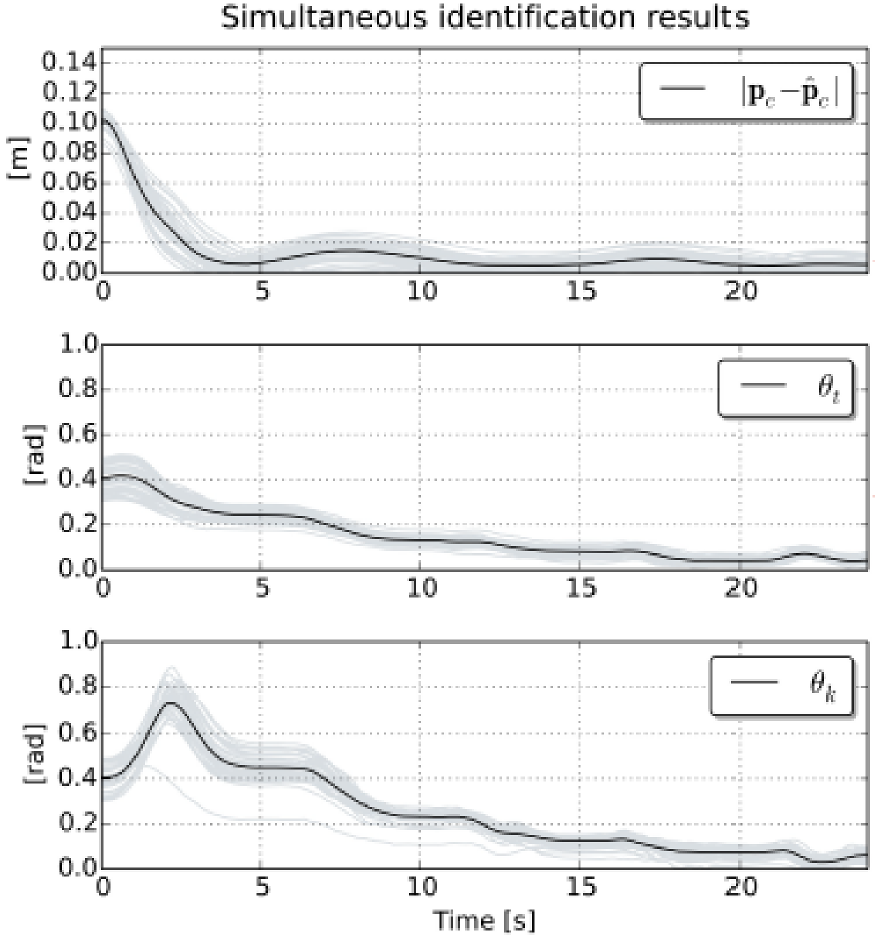
Adaptive mappings for “joint”-axes identification

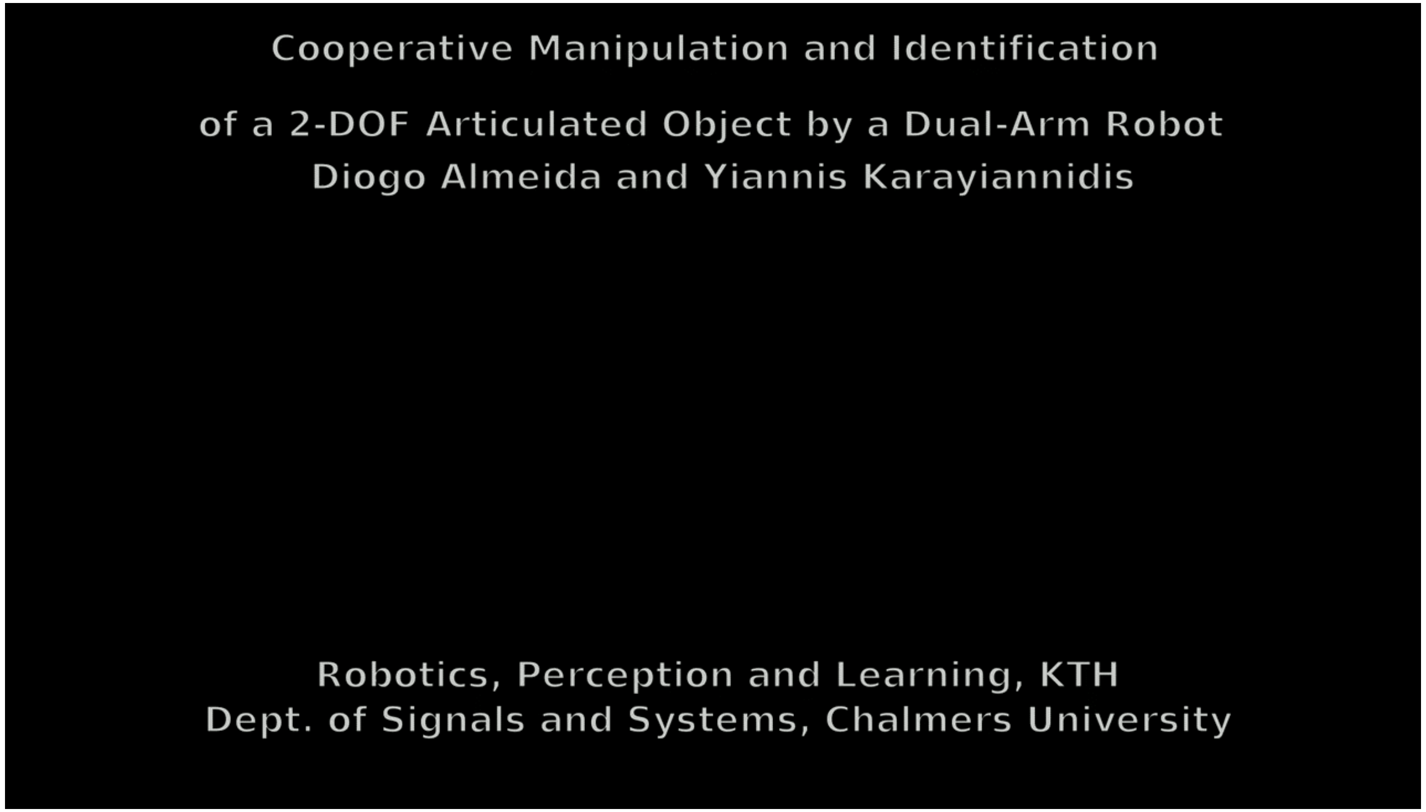




- The control inputs (velocities) are designed based on online estimates and force feedback

Results





Almeida, Karayiannidis, ICRA2018, video

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Discussion

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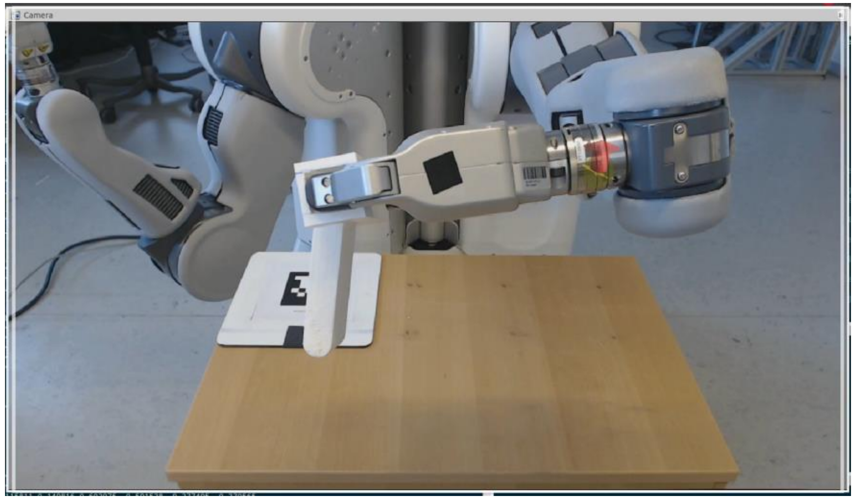
- Force/torque based perception for imperfect situations:
  - Non-rigid grasps
  - Contacts that exert torques
- Exploit both sensors and a learning phase



- Automatic role allocation
- Efficient redundancy exploitation

Linking

$$\mathbf{v}_E = \mathbf{L}(\alpha)\mathbf{W}\begin{bmatrix}\mathbf{v}_1 \\ \mathbf{v}_2\end{bmatrix}$$

Convert to grasp

Assembly with heavy parts: Human Robot Collaboration

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Force sensor

Tool changer

Gripper (3.2 kg)

Ladder-frame (13 kg)

Nominal payload of the robot: 10 (kg)

Assembly with heavy parts: Grasping

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- Grasping needs to address many constraints

  Grippers → Tools
  3D-printed fingers is not the option

  Rigid grasps:
  difficult to achieve

Assembly with heavy parts: Sensing the “co-worker”

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- Grasping needs to address many constraints

  Grippers → Tools
  3D-printed fingers is not the option

  Rigid grasps:
  difficult to achieve

- Real objects are not “sensorized”
- Detect human intention through sensors on the robot

Kinesthetic Perception: Velocity

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Scenario A - Experiment 1

A human holds a wooden board so that it can rotate around virtual axis p_h between hands

A robot estimates the position of p_h while perturbing the other end of the board.

- The motion of the end-effector of the robot is constrained: $\mathbf{\Phi v} = \mathbf{0}$

Karayiannidis, Y., Smith, C., Vina, F., Kragic, D. Online Kinematics Estimation for Active Human-Robot Manipulation of Jointly Held Objects, IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 4872–4878, 2013

- The method cannot be directly applied if the human is compliant or moving

$$\mathbf{\Phi v} = \dot{\mathbf{p}}_h$$

Kinesthetic Perception: Force/torque

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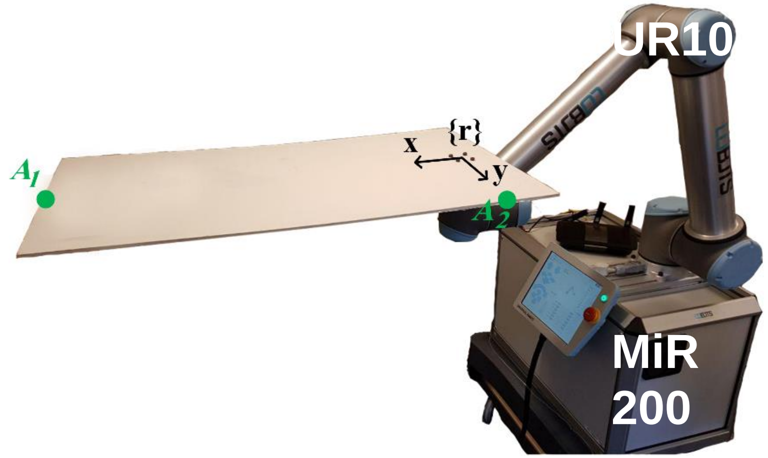
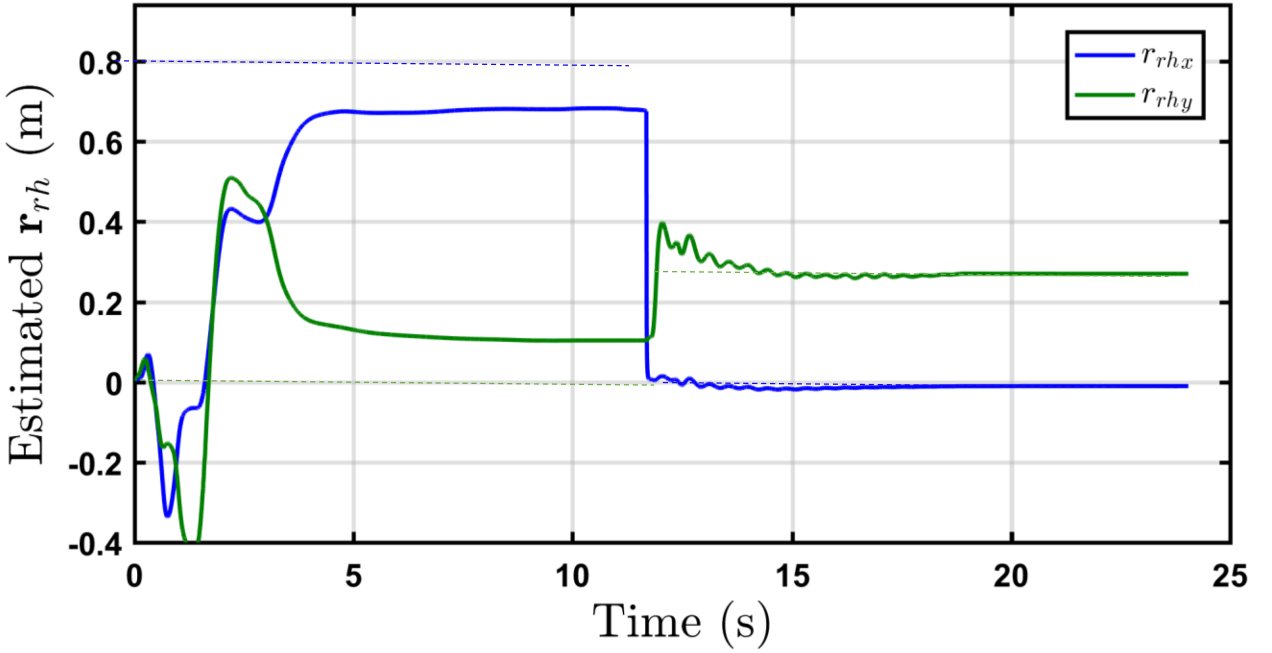


Jaberzadeh R., Karayiannidis, Y., Sjöberg, J. Human-Robot Interaction through a Jointly-held Object based on Kinesthetic Perception, ROMAN, 2018



- Physics-based estimator
- Changing position of the grasp: Resetting the estimator → discard the data related to the previous grasp position.

- Further work needs to be done when the human can exert torques (two hands)

$$^s\boldsymbol{\tau} = {}^s\mathbf{r} \times {}^s\mathbf{f} + {}^s\boldsymbol{\tau}_h$$

Summary

- Dual-arm robots
- Human-Robot Interaction
  - Teaching
  - Collaborating
- Kinesthetic perception – Uncertainty
  Geometry of the interaction
  - Other objects
  - Humans

>> thank_you:)

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Collaborators:

- Ramin Jaberzadeh Ansari
- Jonas Sjöberg
- Diogo Almeida
- Francisco Vina
- Per-Lage Götvall
- Christian Smith
- Danica Kragic
- SARAFun consortium

Projects:

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