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Robot Motion Control During Abrupt Switchings Between Manipulation Primitives

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Acknowledgement

This research has mainly been conducted at

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Institut für Robotik und Prozessinformatik, Prof. Wahl

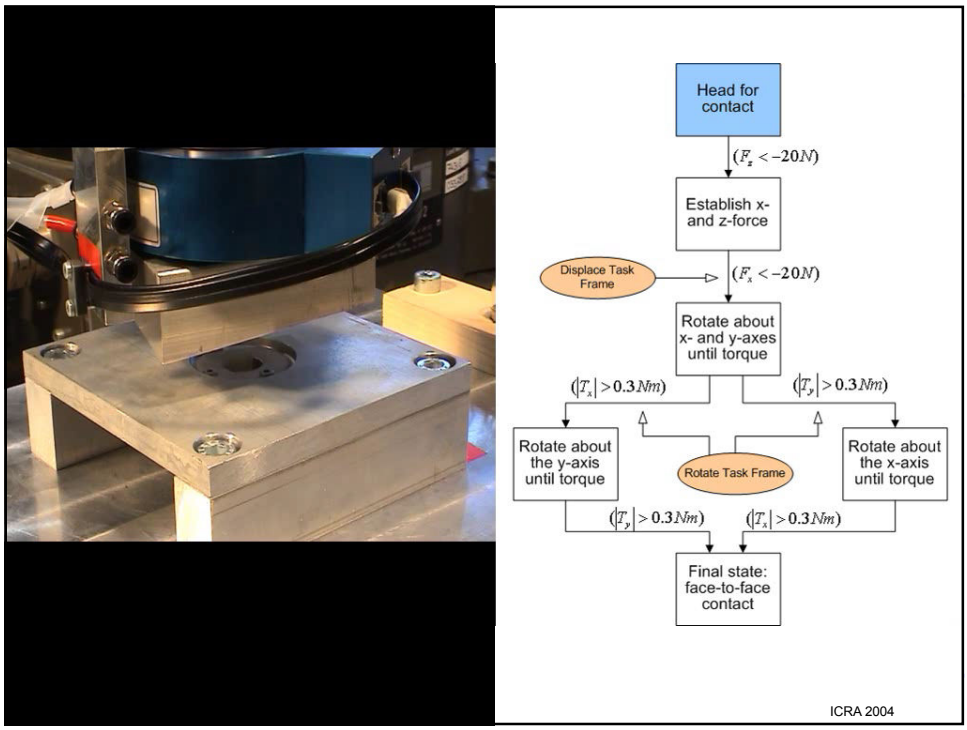
Introduction and Motivation

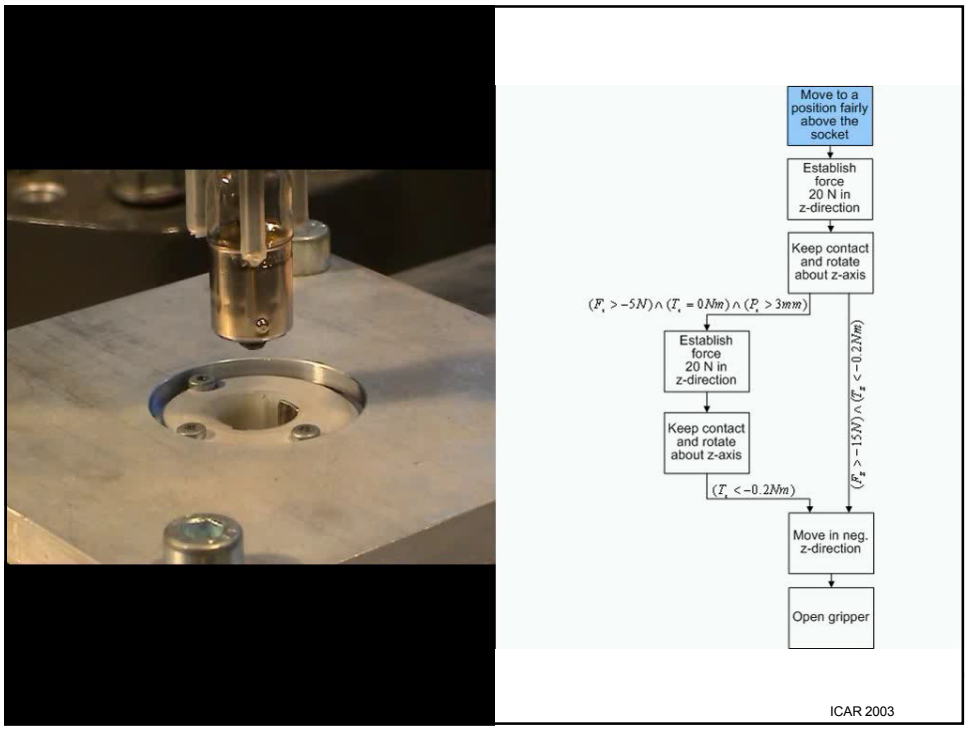
Sensor integration and sensor-based control **at multiple levels** is key for the future advancement of **robotic systems**.

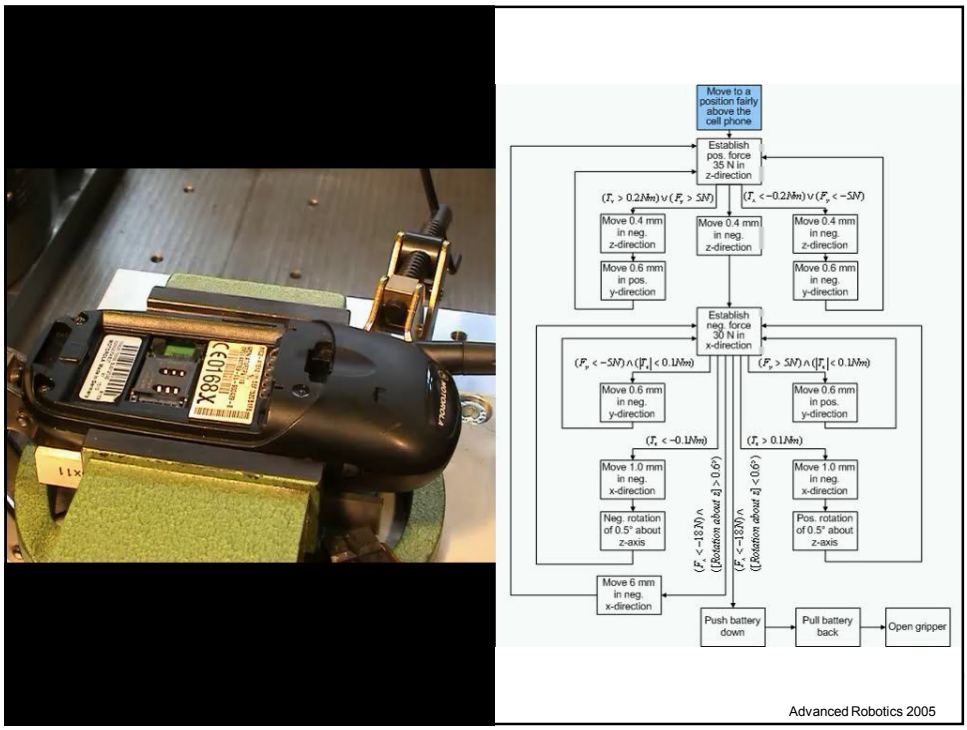
www.omron.com · www.jr3.com · www.theimagingsource.com · www.sick.com · ww.robotic.dlr.de · www.kuka.com · www.honda.com · www.activerobots.com · www.kinemedic.de

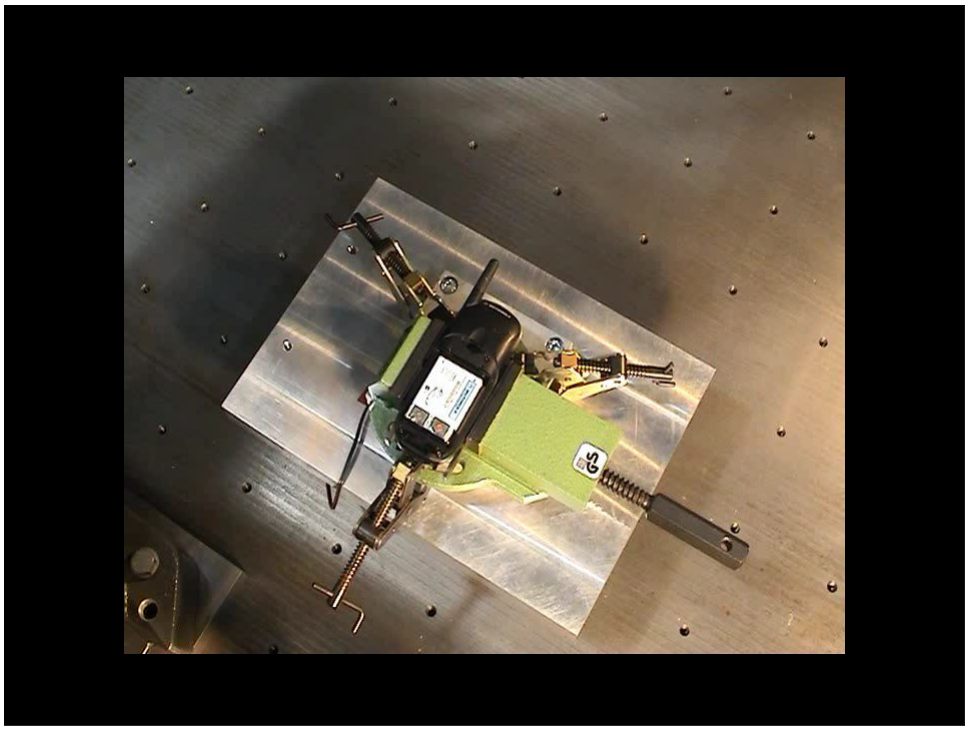
Introduction and Motivation

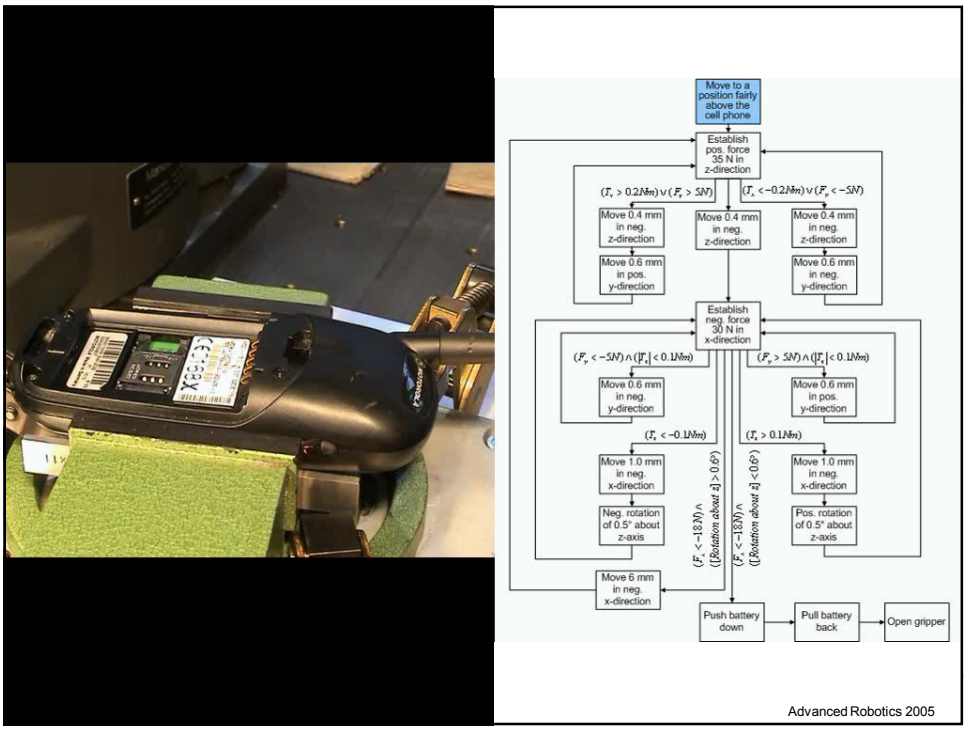
- In general, we distinguish between:
  1. Trajectory-following motions
  2. Sensor-guided motions (sensors in the feedback loops)
     - Force/torque control
     - Visual servo control
     - Distance control
     - …
- In real-world robot applications, systems need to switch between controllers at unforeseen instants.
- The theoretical tool for such switchings is **hybrid switched-system control**.
- How does the real world look like?


Head for contact
$(F_z < -20N)$
Establish x- and z-force
Displace Task Frame
$(F_x < -20N)$
Rotate about x- and y-axes until torque
$(|T_x| > 0.3Nm)$
$(|T_y| > 0.3Nm)$
Rotate about the y-axis until torque
Rotate Task Frame
Rotate about the x-axis until torque
$(|T_y| > 0.3Nm)$
$(|T_x| > 0.3Nm)$
Final state: face-to-face contact
ICRA 2004


Move to a position fairly above the socket
Establish force 20 N in z-direction
Keep contact and rotate about z-axis
$(F_z > -5N) \wedge (T_x = 0Nm) \wedge (P_z > 3mm)$
$(F_z > -15N) \wedge (T_z < -0.2Nm)$
Establish force 20 N in z-direction
Keep contact and rotate about z-axis
$(T_x < -0.2Nm)$
Move in neg. z-direction
Open gripper
ICAR 2003


Move to a position fairly above the cell phone
Establish pos. force 35 N in z-direction
$(T_x > 0.2Nm) \vee (F_z > 5N)$
$(T_x < -0.2Nm) \vee (F_z < -5N)$
Move 0.4 mm in neg. z-direction
Move 0.4 mm in neg. z-direction
Move 0.4 mm in neg. z-direction
Move 0.6 mm in pos. y-direction
Move 0.6 mm in neg. y-direction
Establish neg. force 30 N in x-direction
$(F_y < -5N) \wedge (|T_x| < 0.1Nm)$
$(F_y > 5N) \wedge (|T_x| < 0.1Nm)$
Move 0.6 mm in neg. y-direction
Move 0.6 mm in pos. y-direction
$(T_x < -0.1Nm)$
$(T_x > 0.1Nm)$
Move 1.0 mm in neg. x-direction
Move 1.0 mm in neg. x-direction
Neg. rotation of 0.5° about z-axis
Pos. rotation of 0.5° about z-axis
$(F_x < -18N) \wedge$ ([Rotation about z] > 0.6°)
$(F_x < -18N) \wedge$ ([Rotation about z] < 0.6°)
Move 6 mm in neg. x-direction
Push battery down
Pull battery back
Open gripper
Advanced Robotics 2005





Switching from One MP to Another

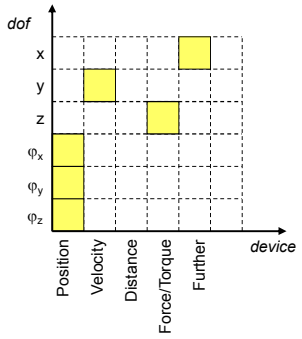
- Controllers **cannot** take over in any situation, e.g.,
  - no valid sensor signal,
  - force control without contact,
  - sudden changes of the environment,
  - sensor malfunctions, or
  - switching to a controller yields heavy jerk.
- Many compliant motion tasks require instantaneous switchings from one controller to another in order to achieve **stability**.
- Requirement: **Autonomous switchings** at the lowest possible control level.
- This framework bases on
- Motion specification by **Manipulation Primitives** (MPs).

[Mason'81, Bruyninckx'96, Finkemeyer'02, Miljghetti'05, Zieliński'10]

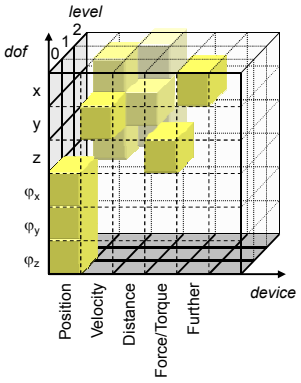
and specifies sensor-guided *and* sensor-guarded robot motions.

The Adaptive Selection Matrix

Classical selection matrix



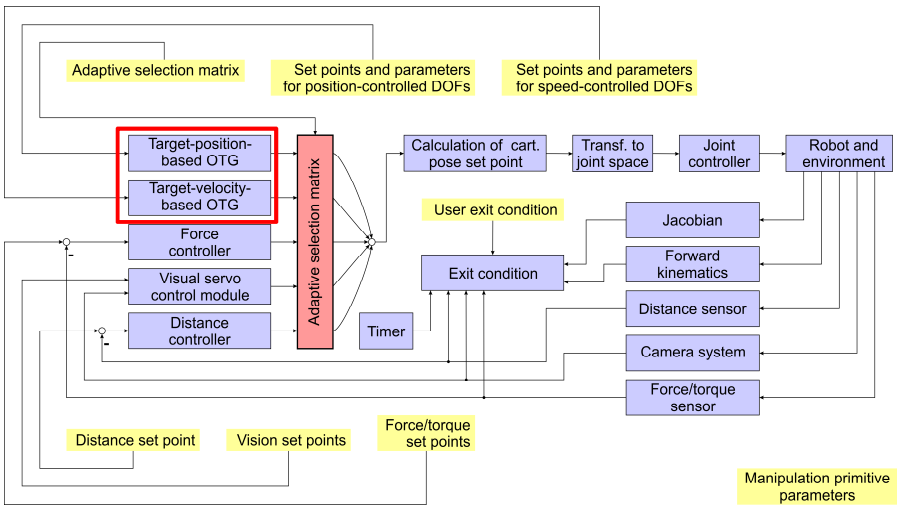
Adaptive selection matrix



An example: ‘Force in z-Direction‘

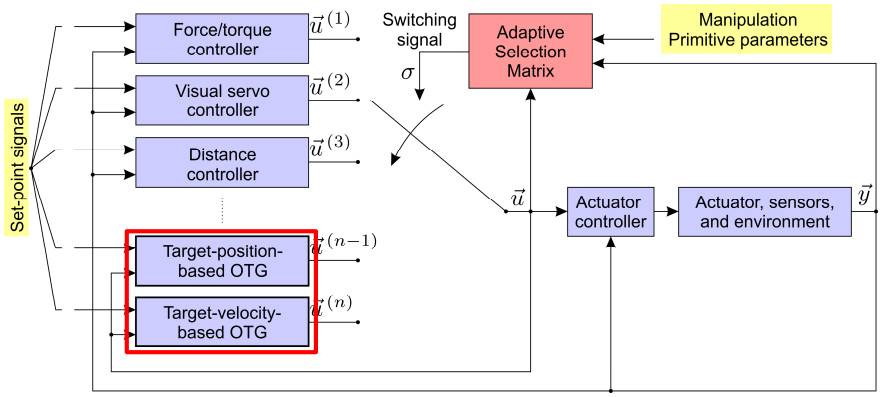
Level 0	Level 1	Level 2
Force	Vision	Velocity

Task Space Control Scheme

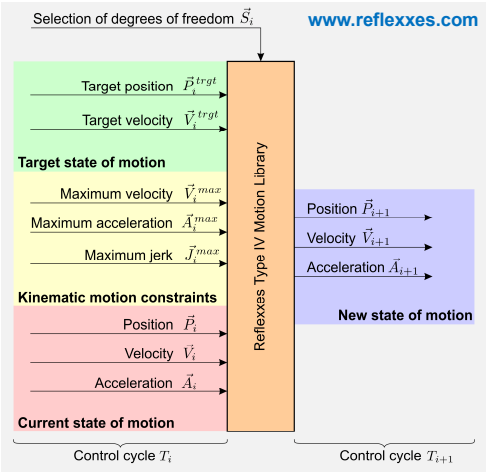


Control Scheme

- Hybrid switched-control (simplified for one DOF)

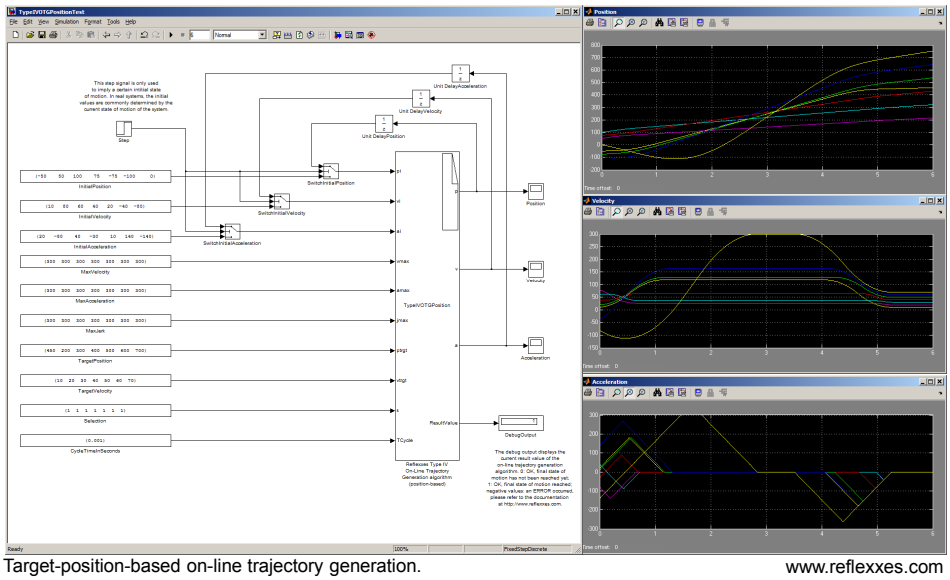


On-Line Trajectory Generation



Target-position-based on-line trajectory generation.

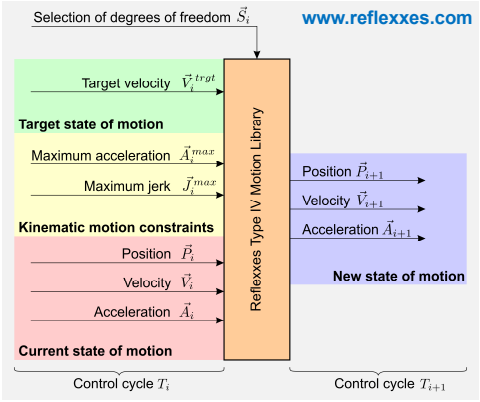
On-Line Trajectory Generation



Target-position-based on-line trajectory generation.

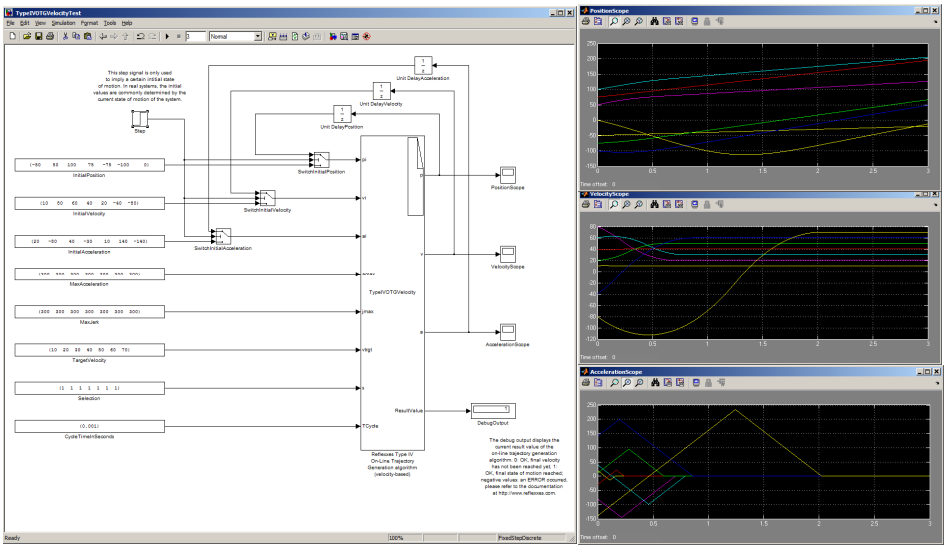
www.reflexxes.com

On-Line Trajectory Generation



Target-velocity-based on-line trajectory generation.

On-Line Trajectory Generation



Target-velocity-based on-line trajectory generation.

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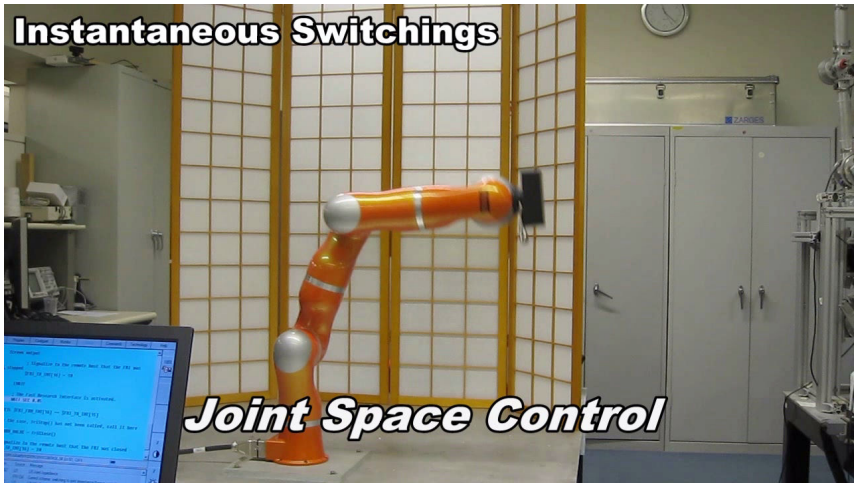
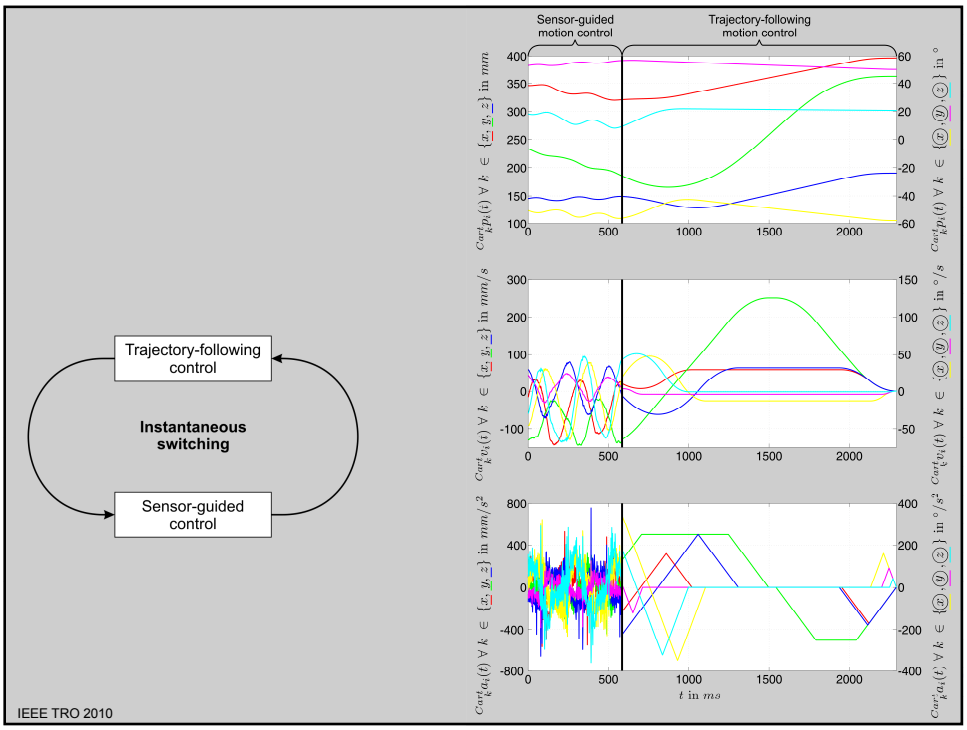
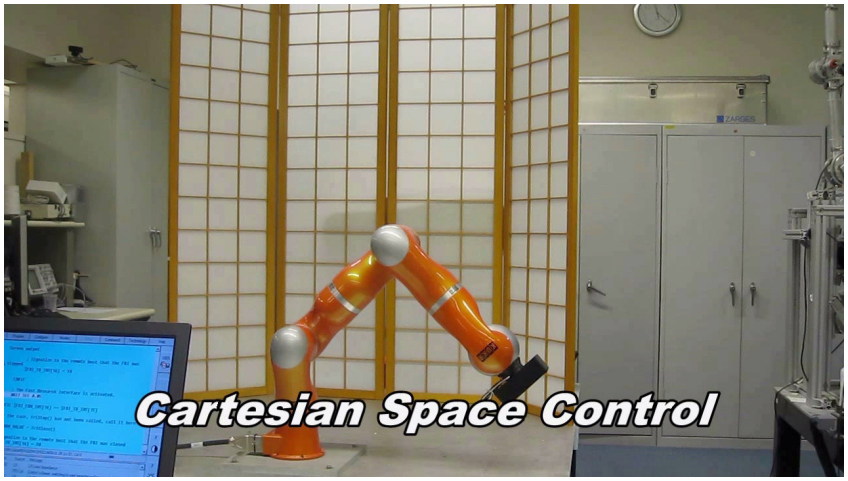
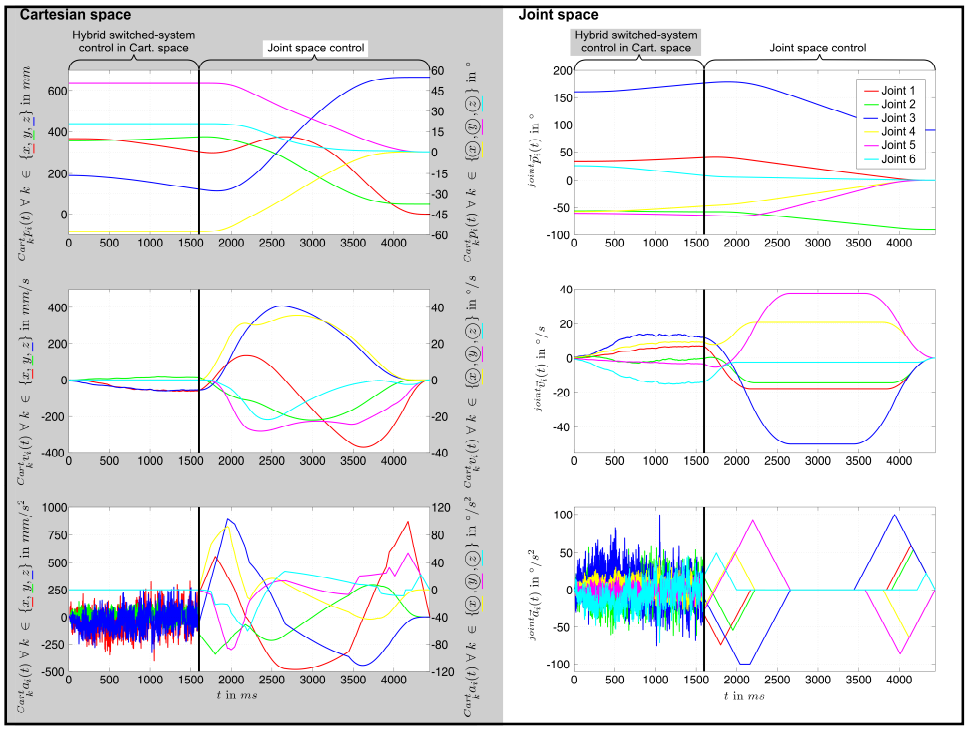
Instantaneous Controller Switching



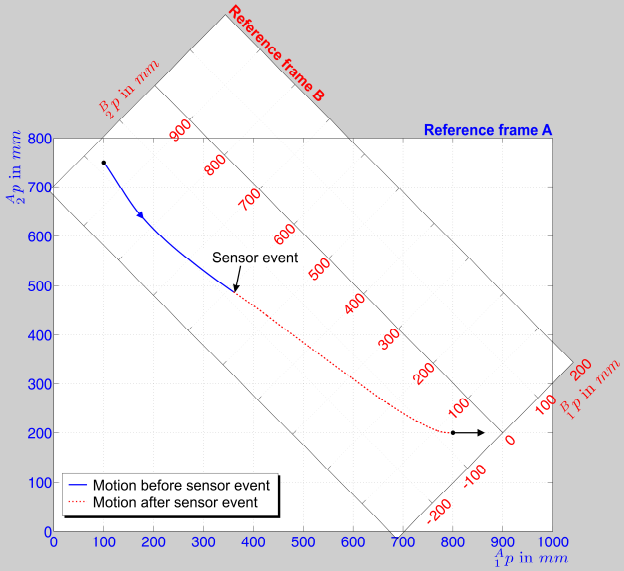


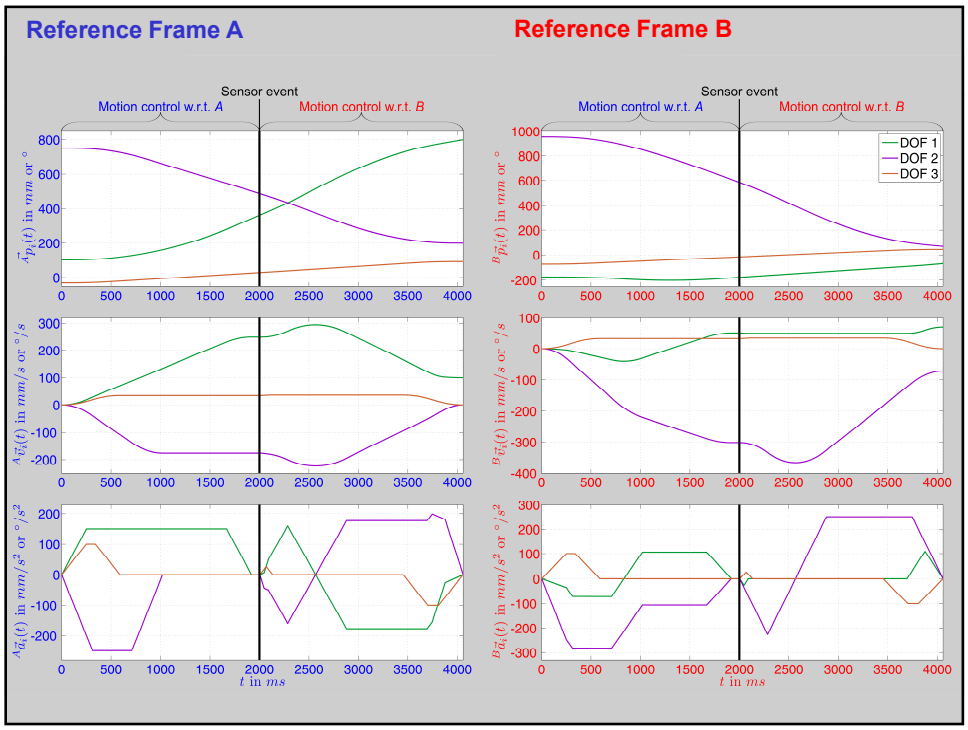
Instantaneous State Space Switching



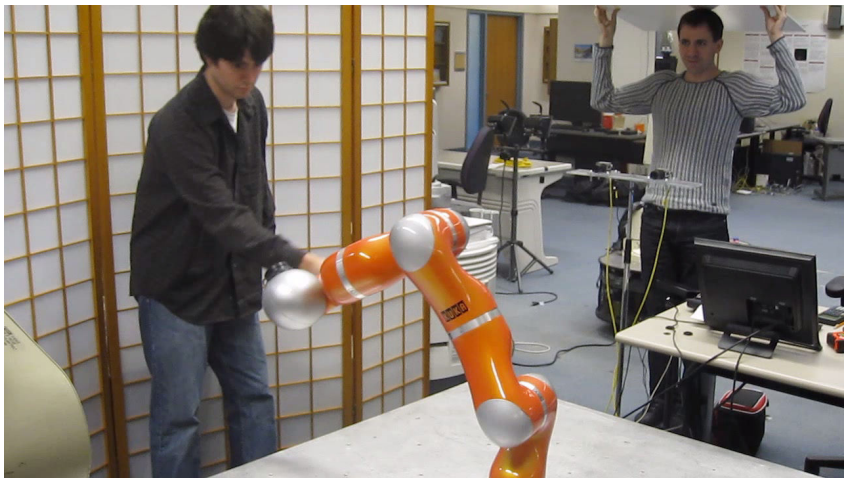


Unforeseen Switching of Reference Frames



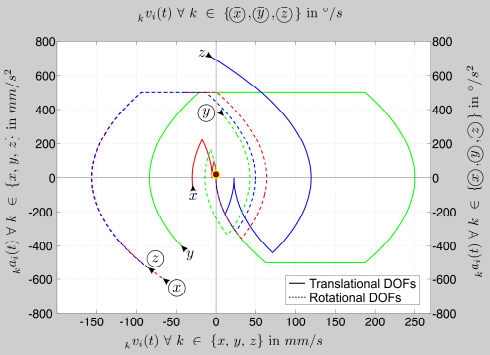


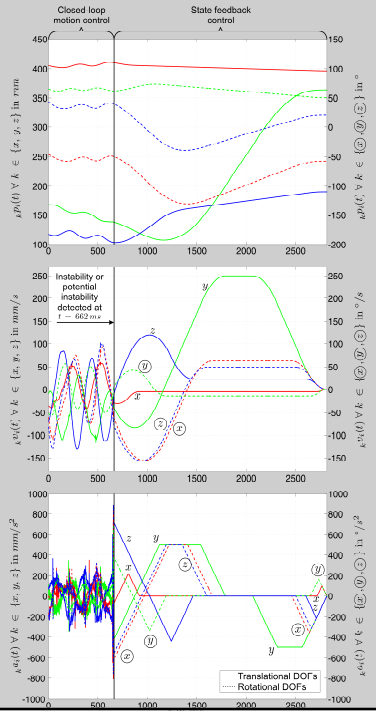
Instantaneous Reactions to Sensor Events



- Stabilizing switched-systems

Velocity-acceleration plane in state space:





ICRA 2010

Summary

- **Manipulation Primitives** as
  - a general interface to **hybrid switched-control** systems for robot motion control, and
  - a "language" to specify sensor-guided **and** sensor-guarded robot motions and tasks (→ adaptive selection matrix).
- **Reflexxes Motion Libraries** provide **on-line trajectory generation** algorithms to
  - guarantee **continuous jerk-limited motions during abrupt switchings** between Manipulation Primitives, and to
  - provide a safe backup controller in a hybrid switched-system.

Literature

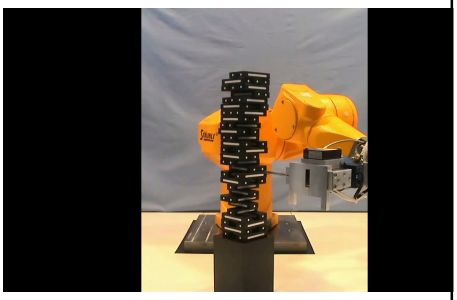
- Please google for ***on-line trajectory generation.***
  - T. Kröger. On-Line Trajectory Generation in Robotic Systems. Springer STAR Vol. 58, 2010.
  - T. Kröger, F. M. Wahl. On-Line Trajectory Generation: Basic Concepts for Instantaneous Reactions to Unforeseen Events. IEEE T-RO, 2010.
  - T. Kröger. On-Line Trajectory Generation: Straight-Line Trajectories. IEEE T-RO, 2011.

Acknowledgements

Deutsche Forschungsgemeinschaft DFG

Thank You for Your Attention!

T. Kroeger, B. Finkemeyer:
Robot Motion Control During Abrupt Switchings Between Manipulation Primitives.



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The End!