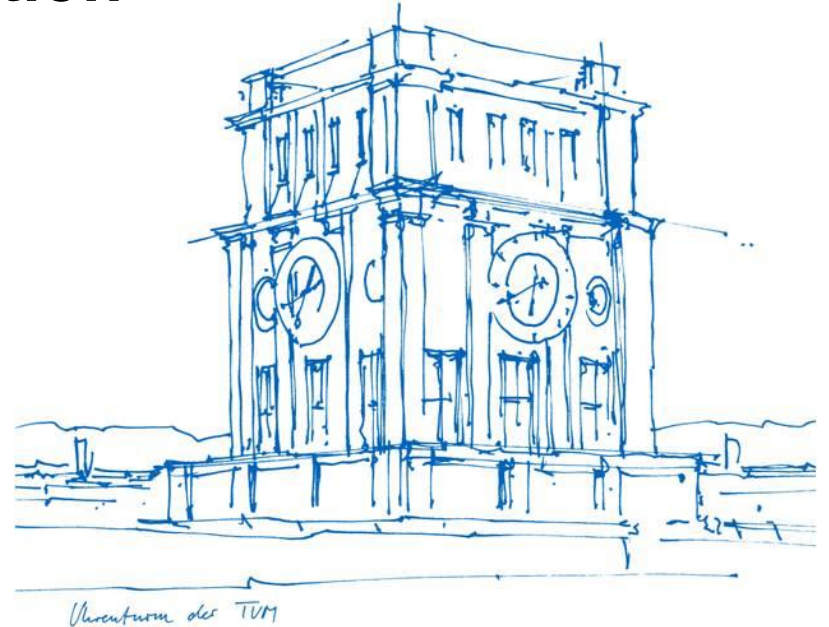


Robot Programming and Control for Human Interaction

Theresa Gräbner,
Daniel Ostermeier,
Jesus Arturo Sol Navarro

10.02.2025



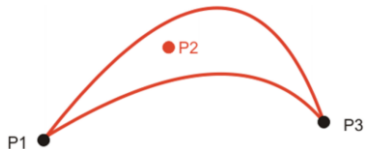
Basic Experiments

PTP and LIN Motions

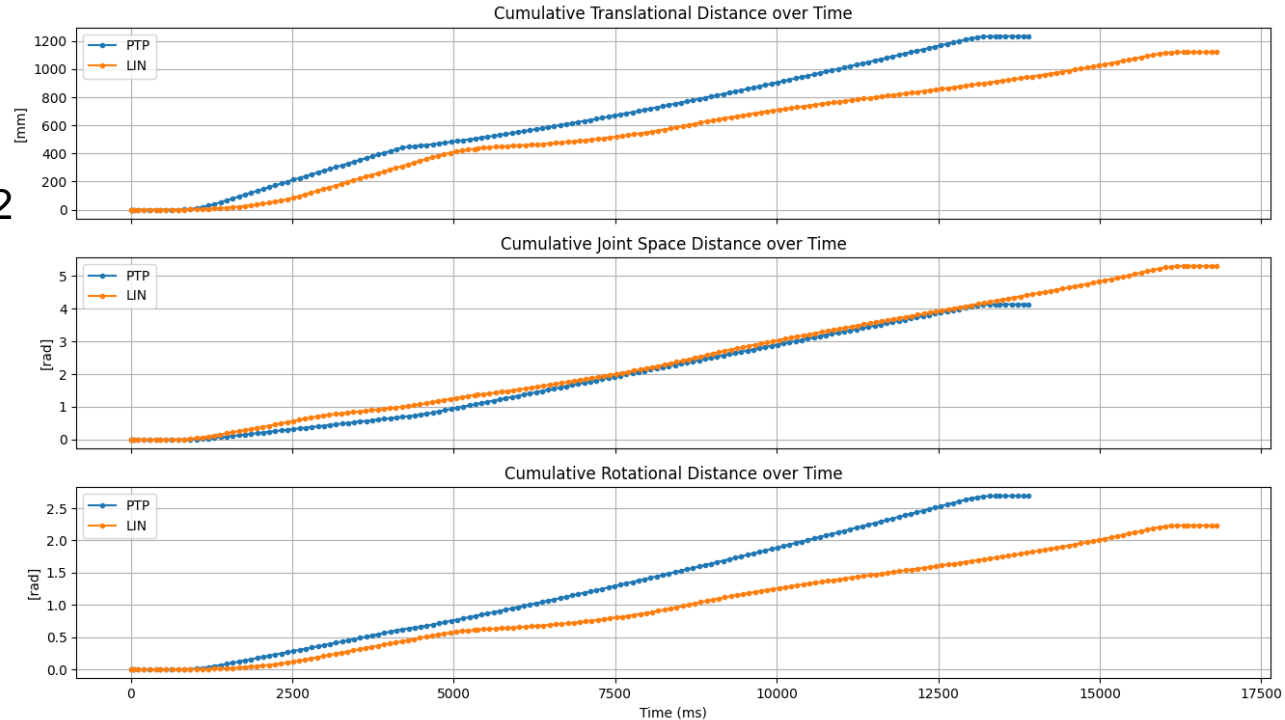
- Three Frames
- 10mm Cartesian blending
- Relative Joint-velocity: 0.2
- **BasicMotions.lin()**



- **BasicMotions.ptp()**

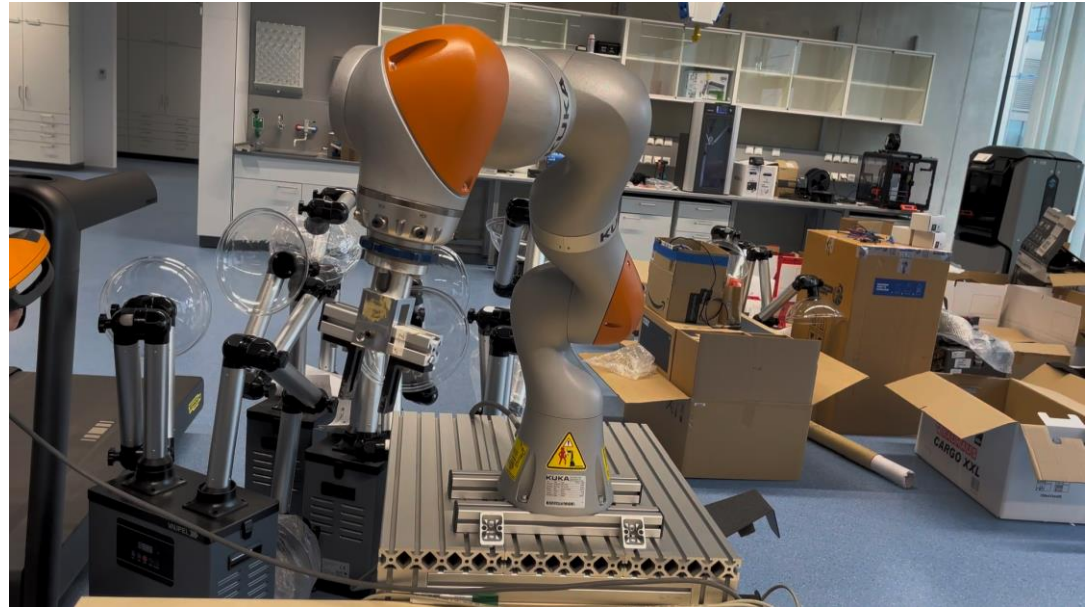


Graphics from Kuka documentation Sunrise.OS 1.5



Nullspace Motion

- Two Frames: PTP Motions
- Including Redundancy Parameters

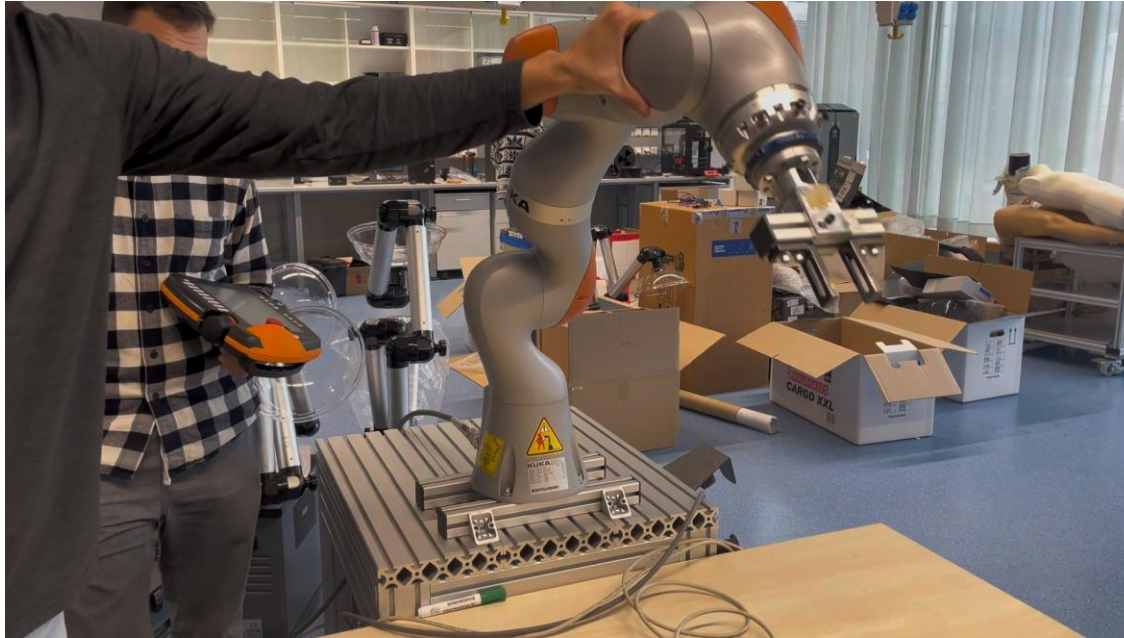


Nullspace Motion

- Two Frames: PTP Motions
- **Excluding Redundancy Parameters**

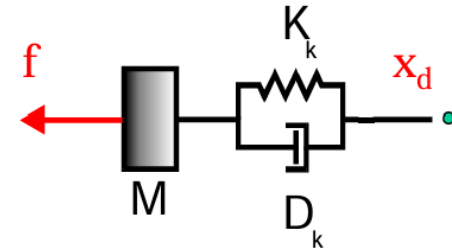


Cartesian Impedance Control



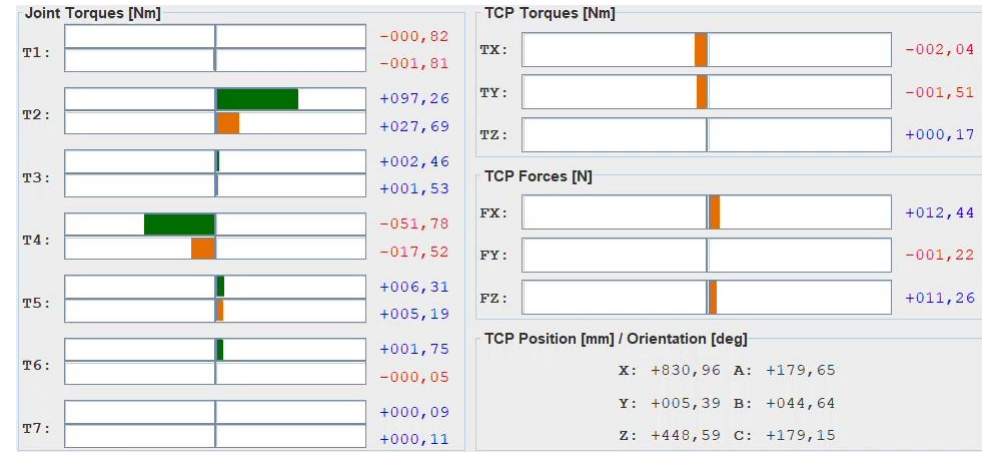
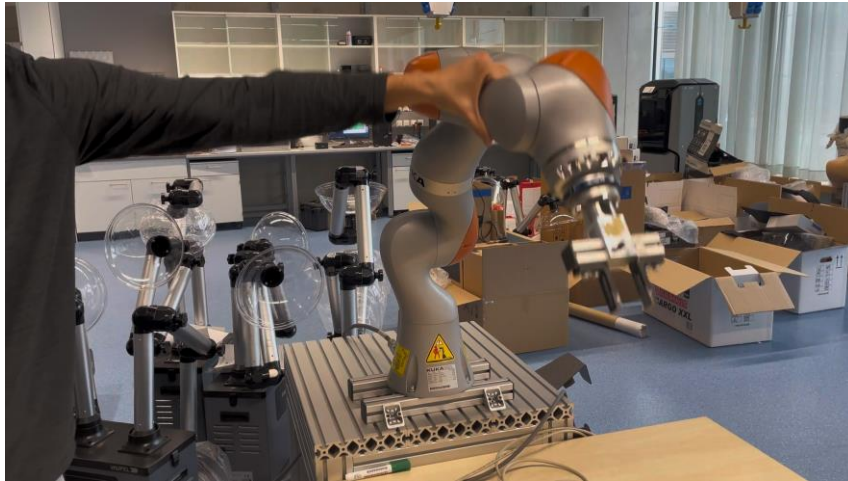
Uniform Damping and Stiffness:

- $K = 2500 \text{ N/m}$, $D=0.3$



Graphic from Lecture slides: Interaction Control

Cartesian Impedance Control



- $K = 1000 \text{ N/m}$, $D=0.3$

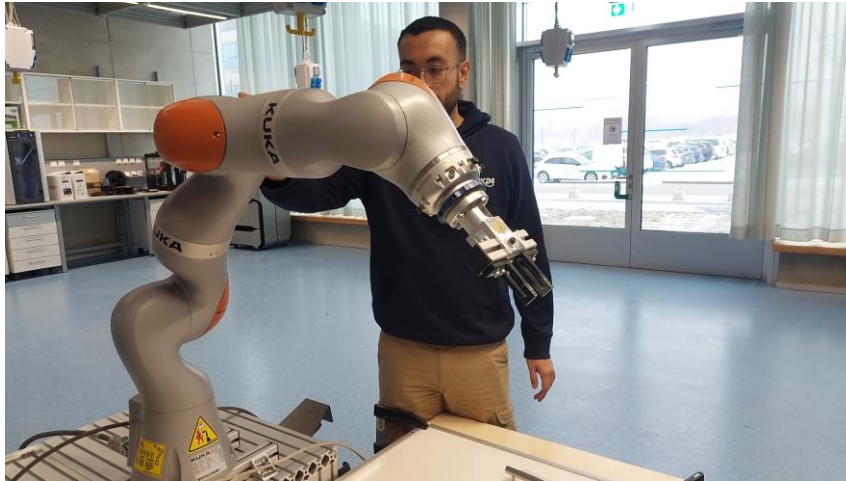
Cartesian Impedance Control



Joint Torques [Nm]			TCP Torques [Nm]		
T1:	<input type="text"/>	+009,61 -000,88	TX:	<input type="text"/>	+000,03
T2:	<input type="text"/>	+059,16 +002,82	TY:	<input type="text"/>	-000,20
T3:	<input type="text"/>	+005,67 -000,13	TZ:	<input type="text"/>	+000,03
T4:	<input type="text"/>	-026,79 -000,46	TCP Forces [N]		
T5:	<input type="text"/>	+000,92 +000,03	FX:	<input type="text"/>	-000,37
T6:	<input type="text"/>	+001,42 -000,09	FY:	<input type="text"/>	+000,01
T7:	<input type="text"/>	+000,05 +000,07	FZ:	<input type="text"/>	-002,69
TCP Position [mm] / Orientation [deg]					
X: +831,13 A: -179,18					
Y: +018,25 B: +044,97					
Z: +454,42 C: +179,35					

- $K = 1000 \text{ N/m}$, $D=0$

Cartesian Impedance Control



Joint Torques [Nm]			TCP Torques [Nm]		
T1:	<input type="text"/>	-000,42 -000,39	TX:	<input type="text"/>	-000,69
T2:	<input type="text"/>	+053,94 +000,54	TY:	<input type="text"/>	+000,15
T3:	<input type="text"/>	+000,58 +000,30	TZ:	<input type="text"/>	-000,02
T4:	<input type="text"/>	-026,42 -000,03	TCP Forces [N]		
T5:	<input type="text"/>	+000,82 +000,24	FX:	<input type="text"/>	-001,03
T6:	<input type="text"/>	+001,64 +000,02	FY:	<input type="text"/>	-001,16
T7:	<input type="text"/>	+000,02 +000,05	FZ:	<input type="text"/>	+001,05
			TCP Position [mm] / Orientation [deg]		
			X: +832,36 A: -180,00		
			Y: -000,14 B: +045,01		
			Z: +454,36 C: -179,99		

Nullspace:

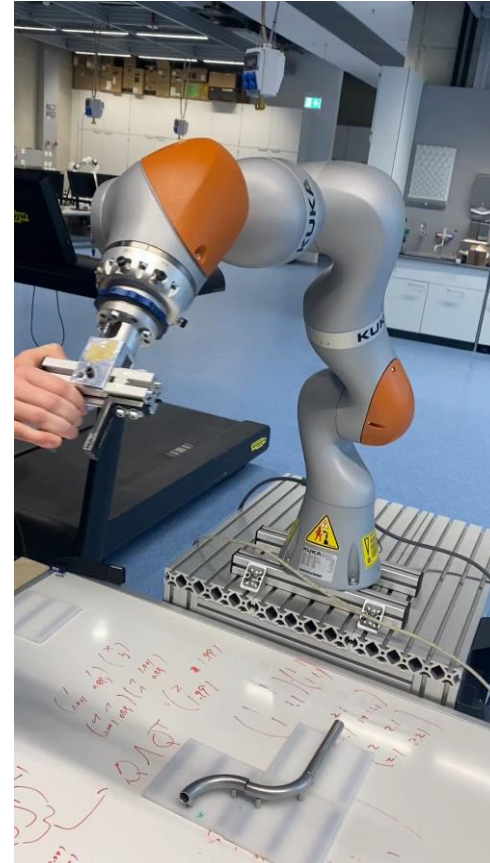
Cartesian DOF:

- $K = 100 \text{ N/m}$, $D=0.3$ • $K = 3000 \text{ N/m}$, $D=0.3$

Cartesian Impedance Control

Different stiffnesses for Cartesian DOF

- Damping factor = 0.7
- **Z-Axis**: $K = 200 \text{ N/m}$
- **X**, **Y** and Rotation: $K = 2500 \text{ N/m}$



Singularities



Joint Torques [Nm]			TCP Torques [Nm]		
T1:	<input type="text"/>	-000,27	TX:	<input type="text"/>	-000,61
	<input type="text"/>	-000,23	TY:	<input type="text"/>	+000,32
T2:	<input type="text"/>	+027,53	TZ:	<input type="text"/>	+000,13
	<input type="text"/>	+000,46			
T3:	<input type="text"/>	-000,00			
	<input type="text"/>	+000,02			
T4:	<input type="text"/>	-027,10			
	<input type="text"/>	+000,01			
T5:	<input type="text"/>	+000,79			
	<input type="text"/>	+000,23			
T6:	<input type="text"/>	+002,63			
	<input type="text"/>	+000,21			
T7:	<input type="text"/>	+000,08			
	<input type="text"/>	+000,13			

TCP Forces [N]		
FX:	<input type="text"/>	-000,81
FY:	<input type="text"/>	-001,28
FZ:	<input type="text"/>	+001,05

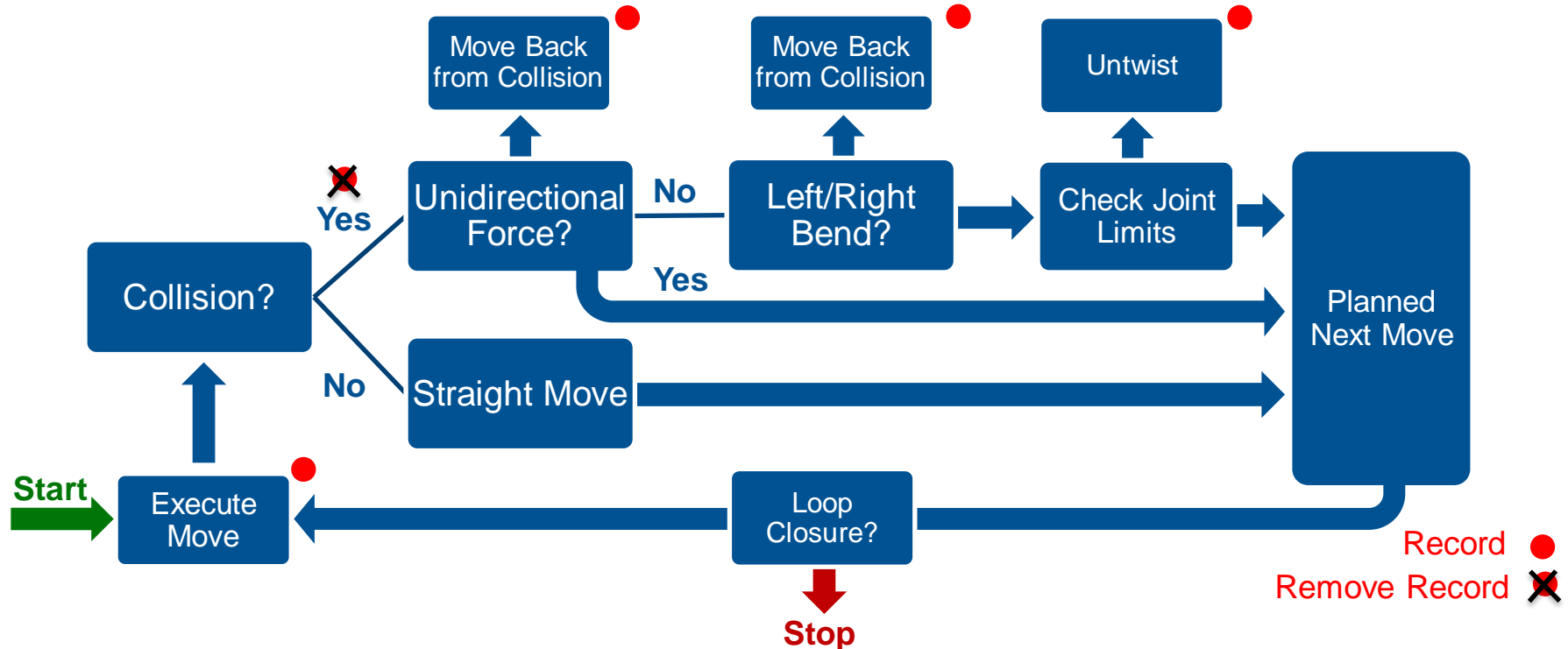
TCP Position [mm] / Orientation [deg]		
X:	+720,18	A: -179,97
Y:	-000,02	B: +077,48
Z:	+668,90	C: -179,97

- Cartesian forces get very large near singularities
- Why? => Inversion of singular Jacobian

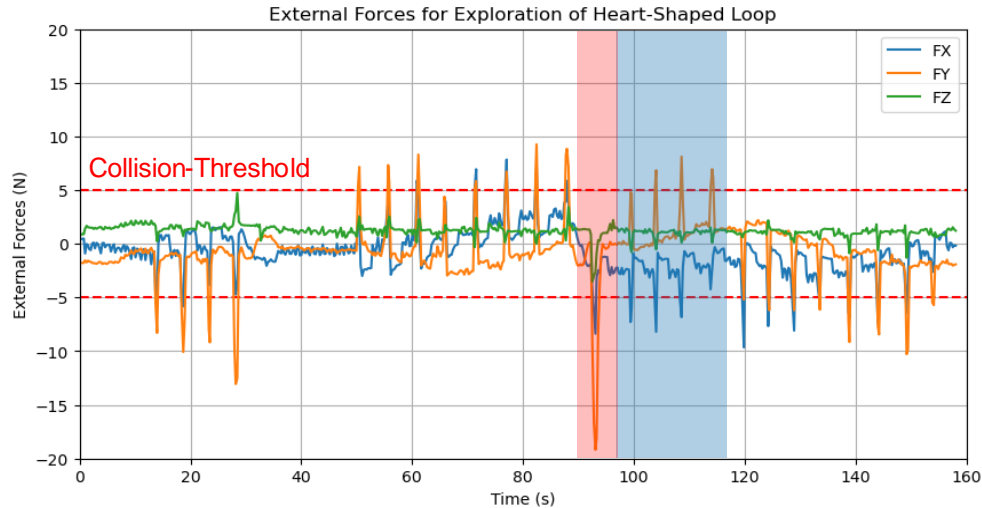
$$F = J^{\#-1} * \tau$$

The Wireloop: Algorithm & Experiments

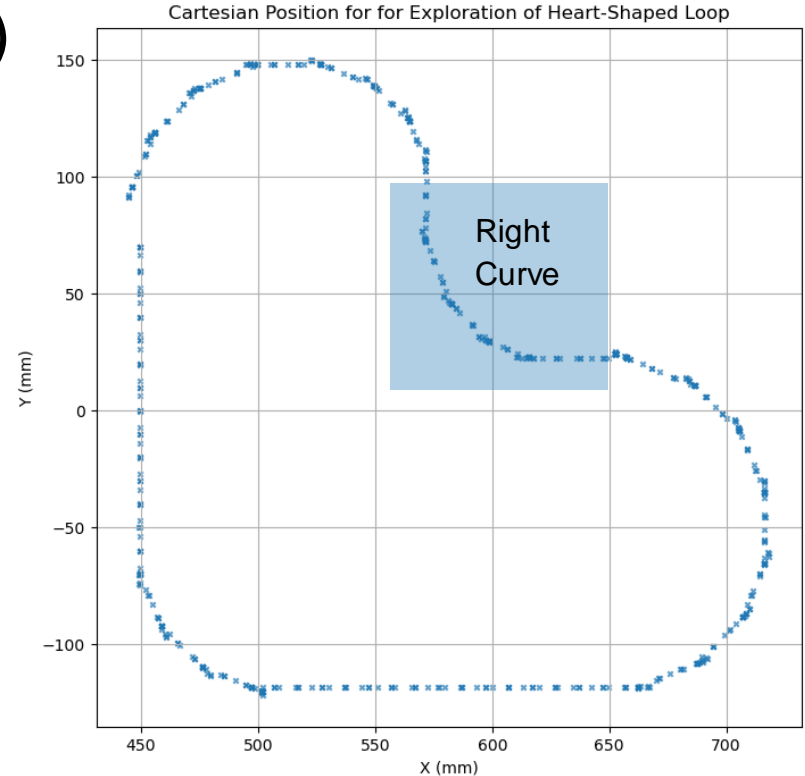
Wireloop: Algorithm



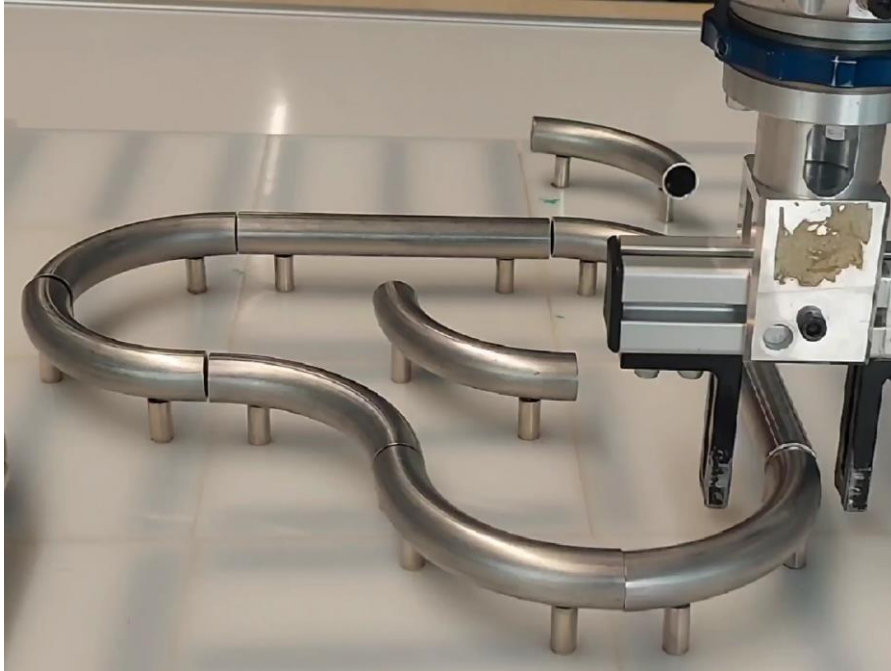
Heart-Shaped Loop (Exploration)



- 4 collisions per quarter of circle
- Rotation of $\pi/8$ per collision
- Repositions after first curve and before right curve
- Collides after repositioning before right curve



Heart-Shaped Loop: Exploration + Replay



Exploration:

- Differentiates right and left curve
- Collides after reposition maneuver

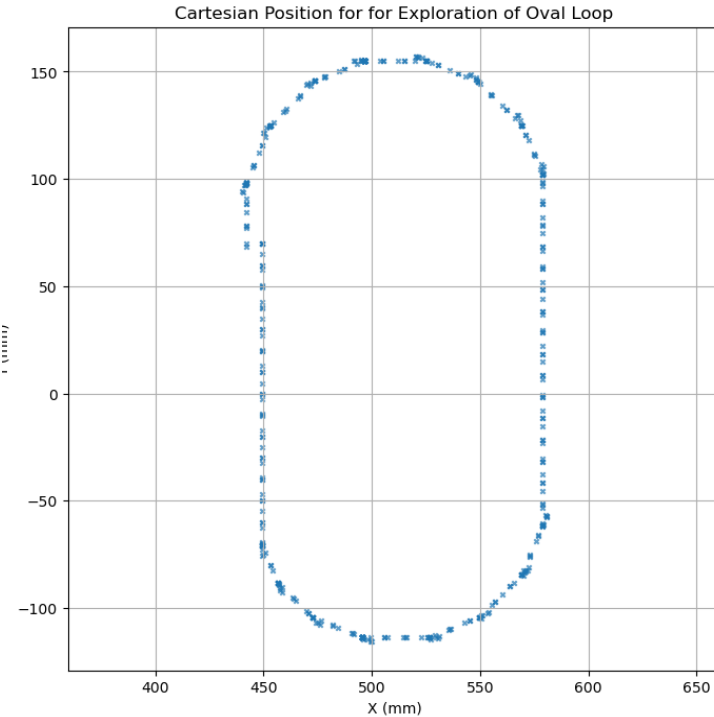
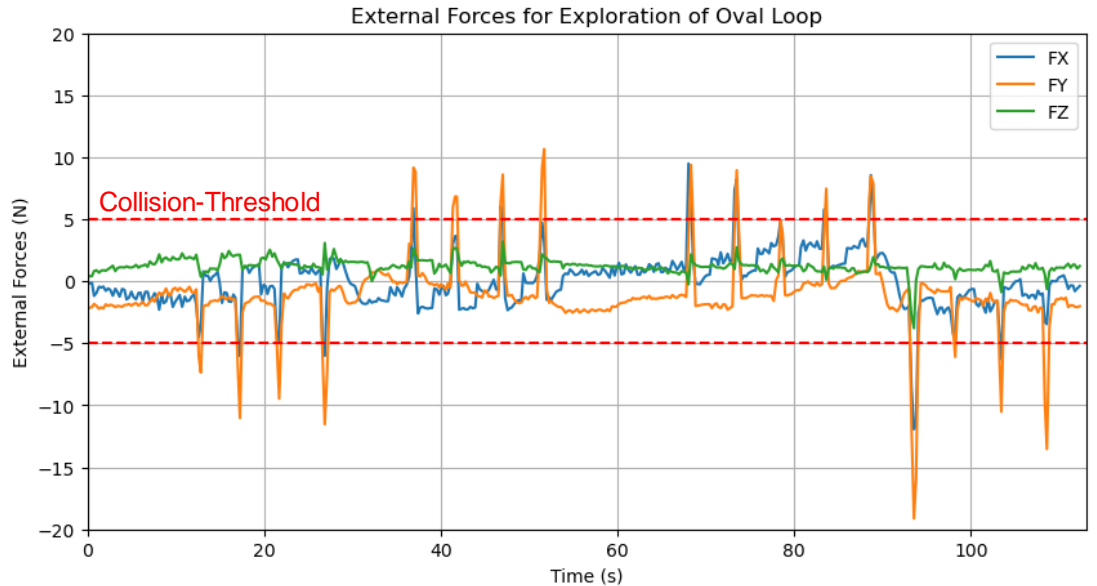
Replay:

- Collides after reposition maneuver
- Rest of motion collision free

Solution to Collision after repositioning:

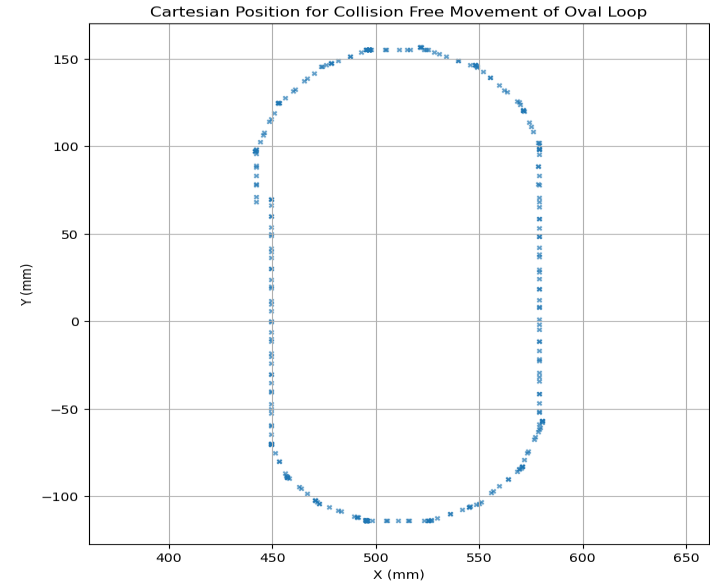
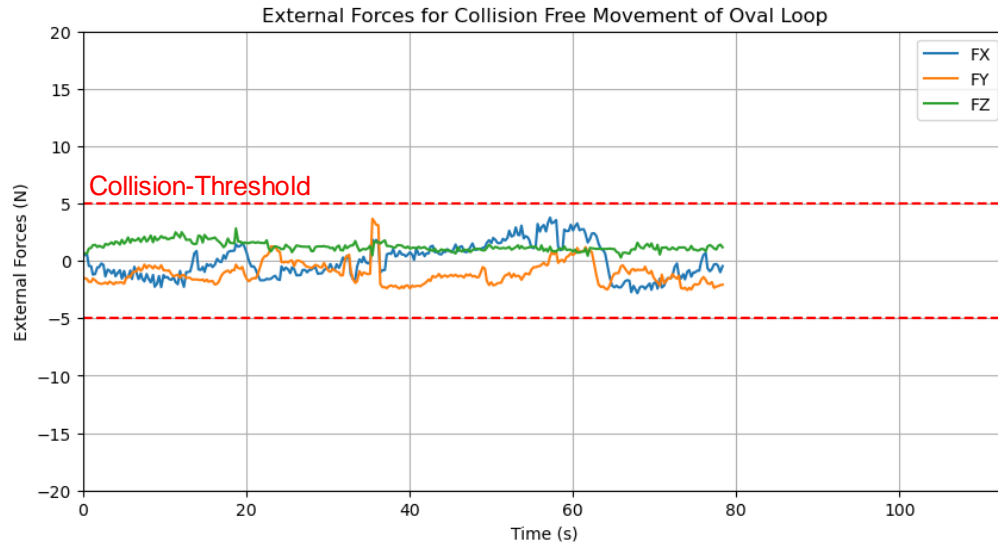
- Reposition only after moving slightly back from collision point

Oval Wireloop (Exploration)



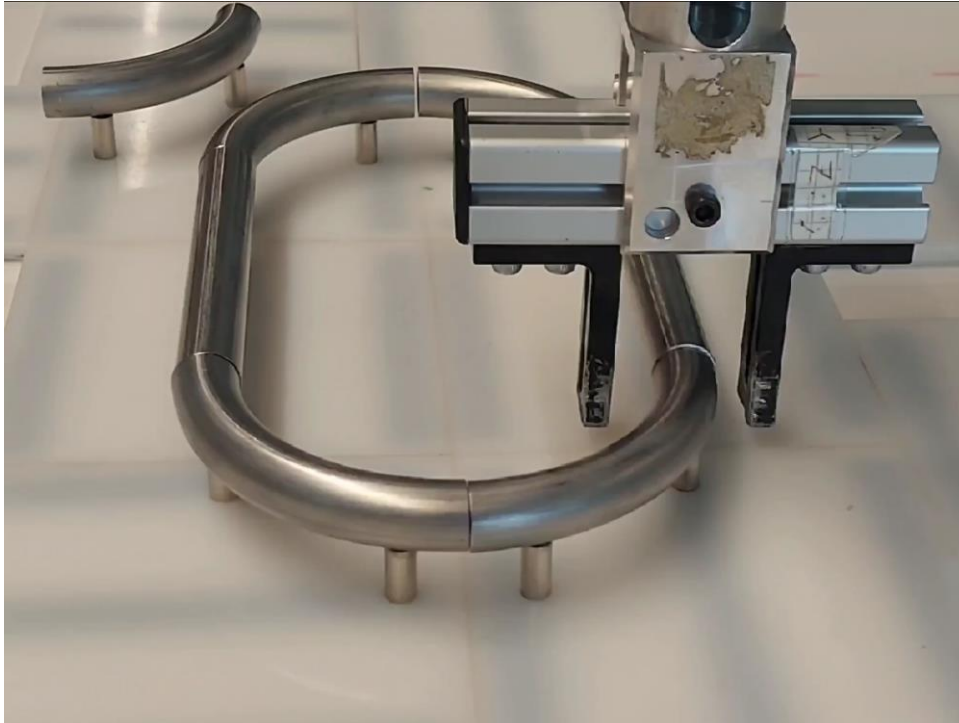
- Repositions after first curve and before last curve
- Threshold line (+5/-5)

Oval Wireloop (Replay)



- Replay takes less time
- Collisions under the 5 N threshold
- Noise in cartesian Forces -> Threshold for Break Condition = 5N

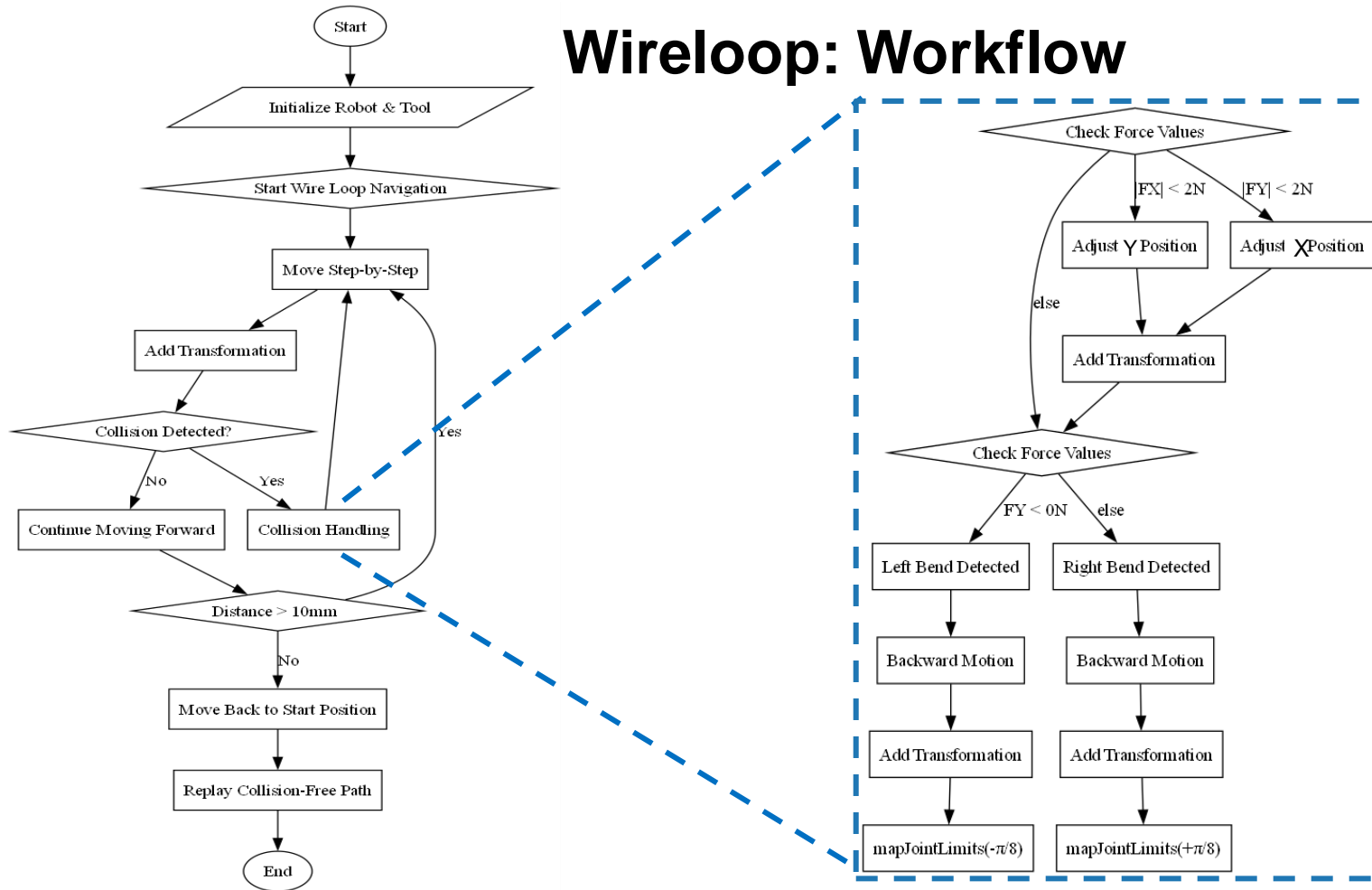
Video: Oval with Exploring + Replay



- **Successfully** Exploration
- **Collision-free** Replay
- **Potential Improvement:**
 - **Add cartesian blending**

Thanks for your attention!
Questions? Ask ahead!

Wireloop: Workflow



Wireloop: Reposition Handling

