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Safe Collision and Clamping Reaction for Parallel Robots During Human-Robot Collaboration

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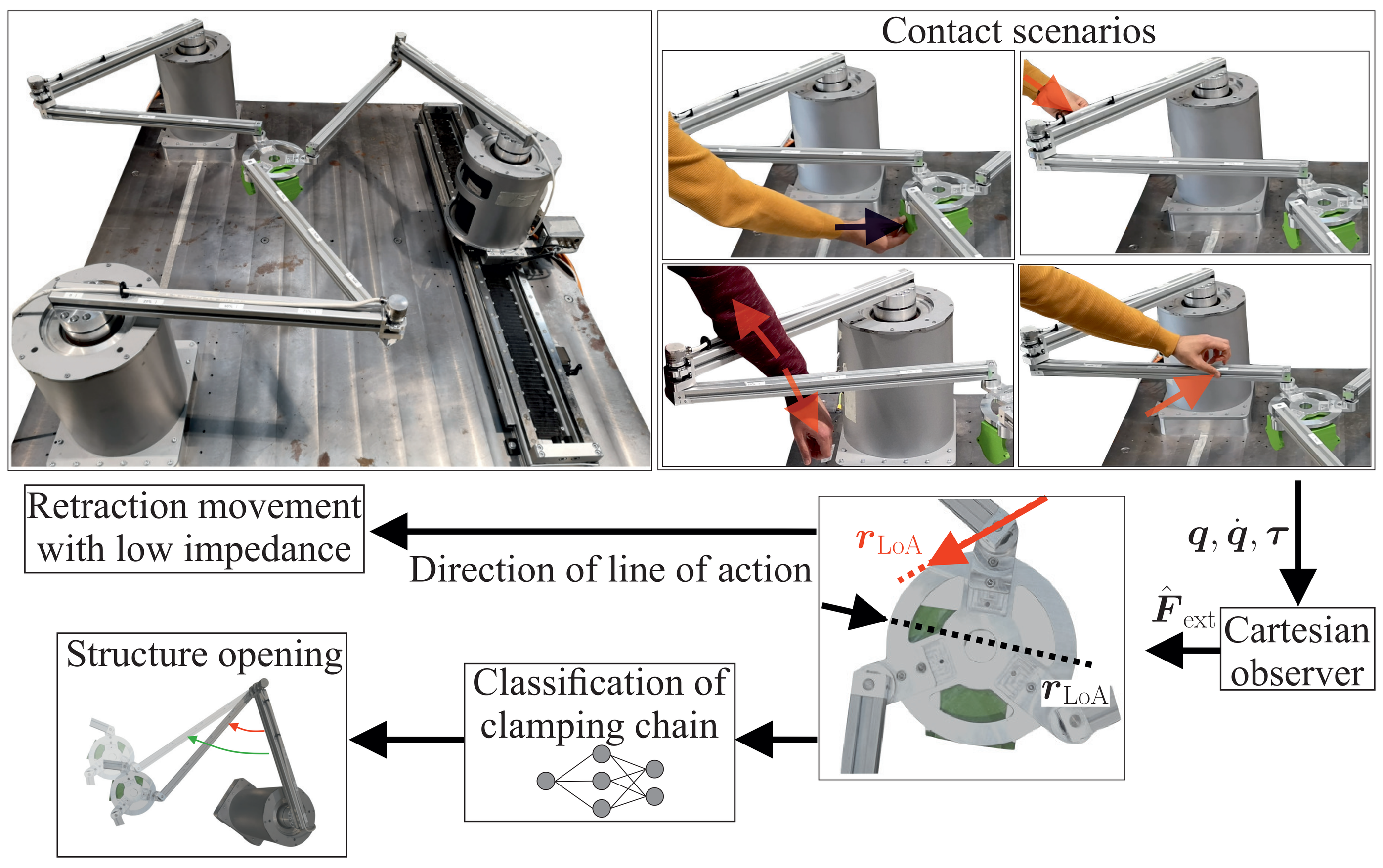
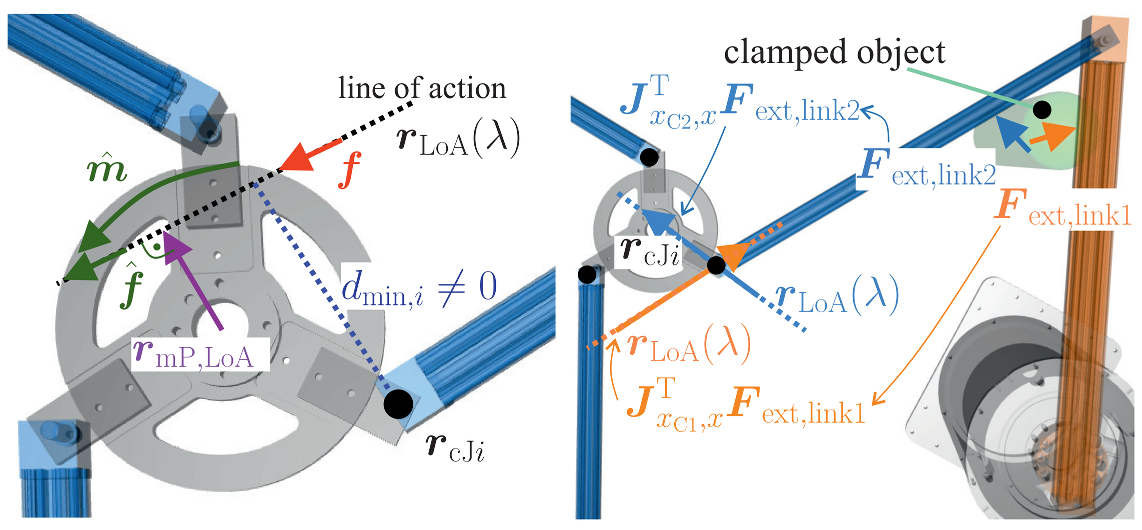
Research Question & Contributions

- Parallel robots are characterized by drives mounted fixed to the base. Reduced moving masses allow higher speeds while maintaining the same energy thresholds regarding human-robot collaboration. Due to the parallel kinematic chains, the risk of contact increases. → **How should a parallel robot react to collisions and clamping on the structure to ensure safety in human-robot collaboration?**
- Feedforward neural networks distinguish clamping and collision, as well as predict the clamping kinematic chain
- Trajectory planning and control in the operational space allow the decoupling of the translational and rotational coordinates for a retraction movement and an opening of the clamping structure



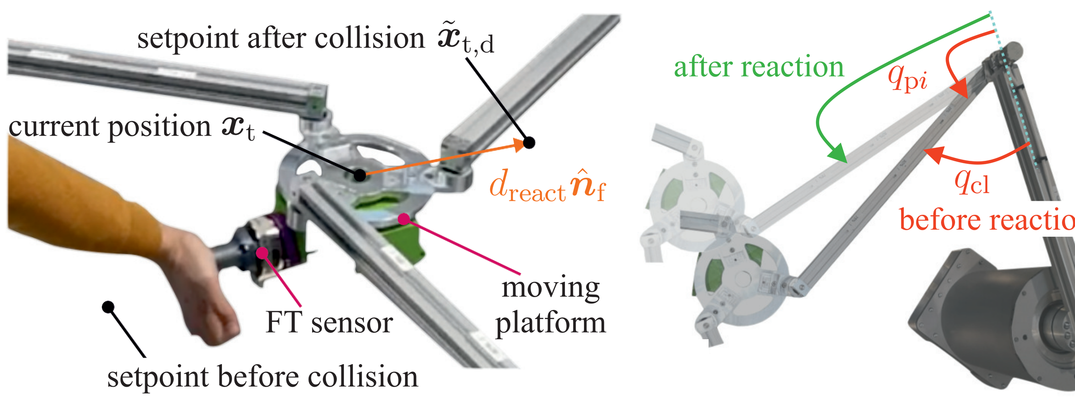
Reaction Strategies for Collision & Clamping

Kinetostatic Analysis



- Translational platform coordinates for retraction movement along $\hat{\boldsymbol{n}}_{\mathrm{f}} = \hat{\boldsymbol{f}} / ||\hat{\boldsymbol{f}}||_2$
- Rotational platform coordinates for opening clamping joint

Core Idea



Ground truth \ Prediction	Clamping	Collision
Clamping	80.1%	19.9%
Collision	14.9%	85.1%

Ground truth \ Prediction	C1	C2	C3
C1	91.8%	0.2%	8.0%
C2	0.3%	95.6%	4.1%
C3	1.3%		98.7%

Neural networks classify clamping leg chain

Algorithm

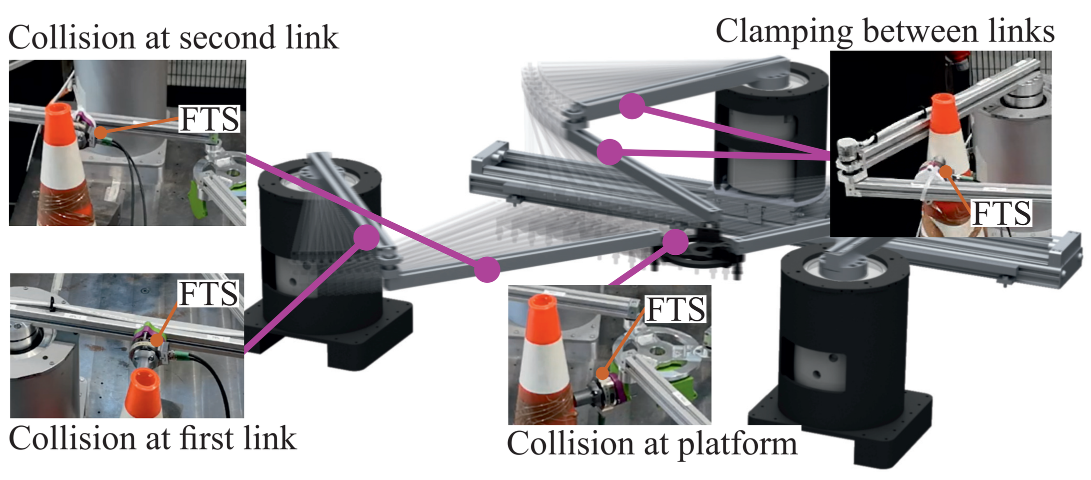
Algorithm 1: Reactive motion planner

Input : $\hat{\boldsymbol{F}}_{\mathrm{ext}}, \boldsymbol{q}, \boldsymbol{x}, \boldsymbol{\epsilon}_{\mathrm{r}}, \boldsymbol{\epsilon}_{\mathrm{g}}$
Output: Desired platform trajectory and controller's stiffness

if $|\hat{F}_{\mathrm{ext},j}| \geq \epsilon_{\mathrm{g},j}$ **then**
  // Zero-g mode
else if $|\hat{F}_{\mathrm{ext},j}| \geq \epsilon_{\mathrm{r},j}$ **then**
  // Retraction movement
  $b_{\mathrm{clamp}} \leftarrow$ Binary output of 1st FNN for clamping classification;
  if b_{clamp} **then**
    Clamping chain classified by 2nd FNN;
    // Structure opening
  end
else
  // No reaction
end

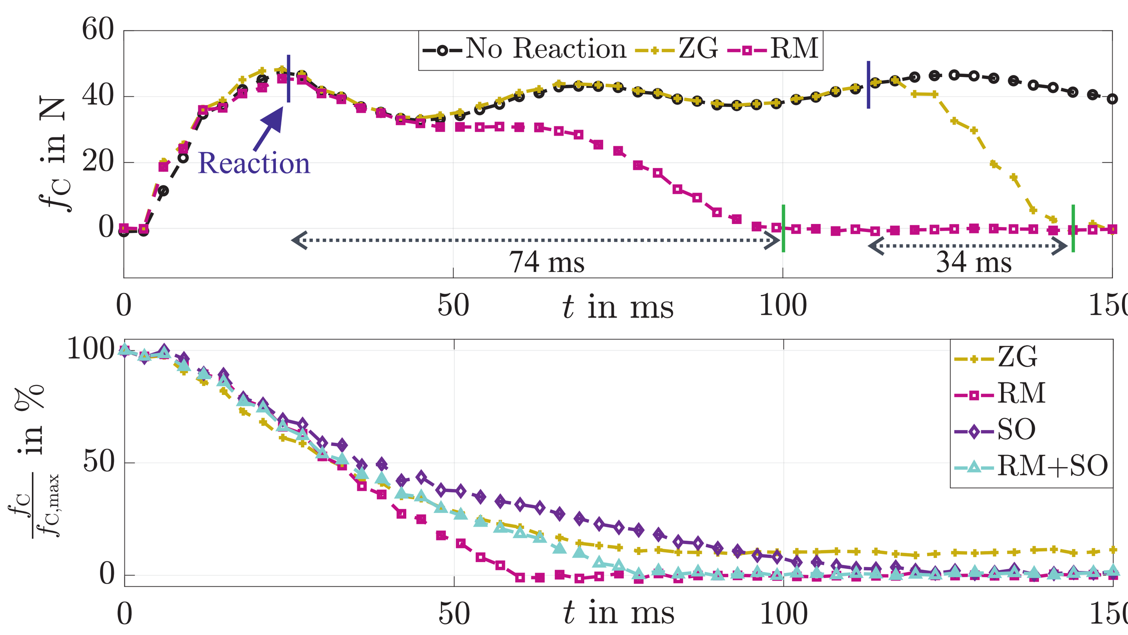
Reaction Methods in Contact Experiments

Collision and Clamping Contacts



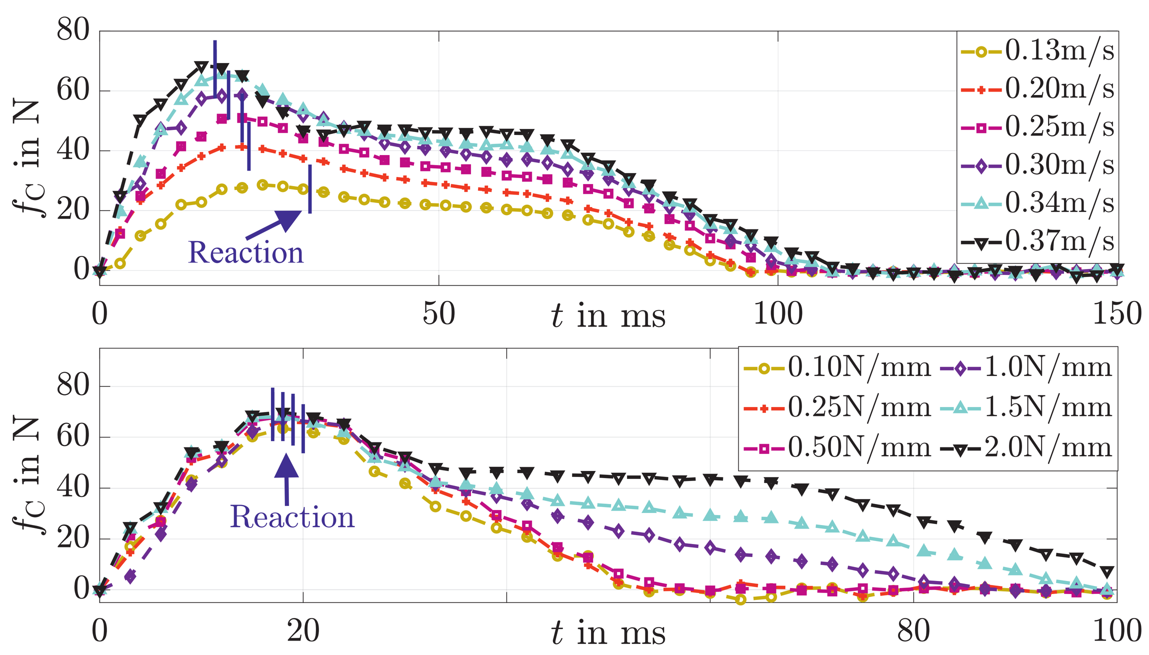
- Evaluation of reactions to contacts at different platform velocities 0.05–0.42 m/s and reaction stiffnesses 0.1–2 N/mm
- Measuring forces for comparison of maximum force, duration and removal of contact

Comparison of Different Reactions



Contact experiments consist of collision at the platform (top), first and second link, clamping (bottom)

Variation of Speed and Control Stiffness



- Contact removal in less than 130 ms
- Maximum force is 70 N by 0.37 m/s (comp. to TS 15066 280 N for hum. hand)

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