Active Constraints Using Vector Field Inequalities for Surgical Robots

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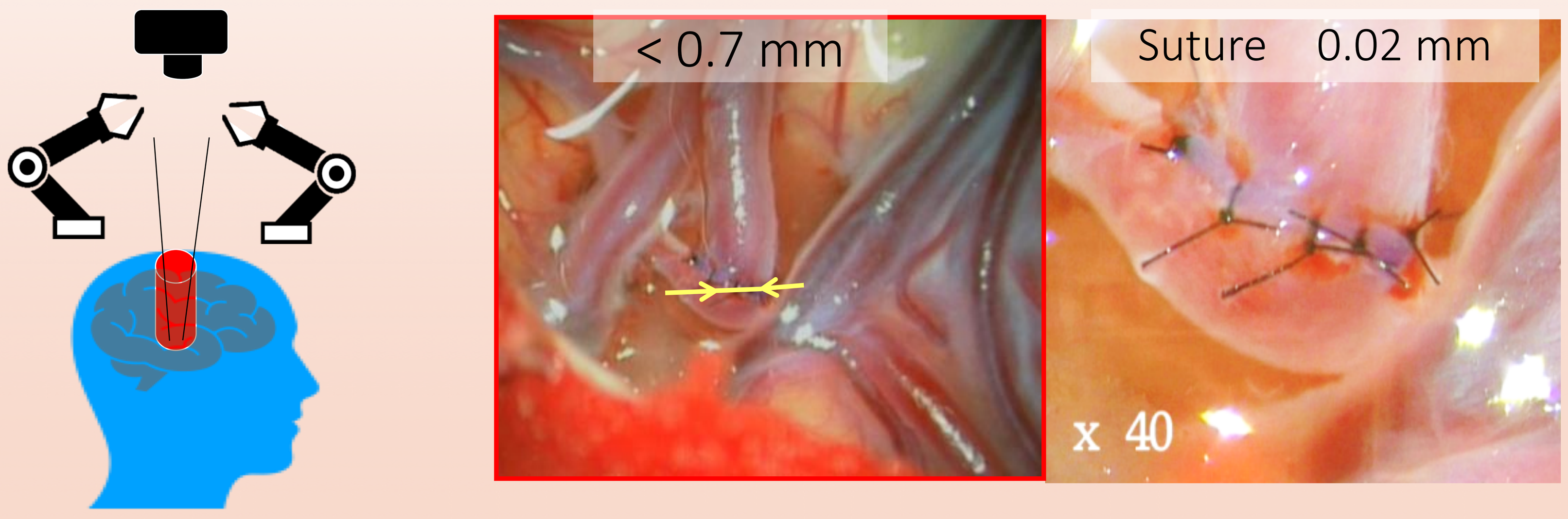
① Introduction

Surgical procedures in deep and narrow regions of the body require **active constraints/virtual fixtures** for increased **safety** and **operability.**

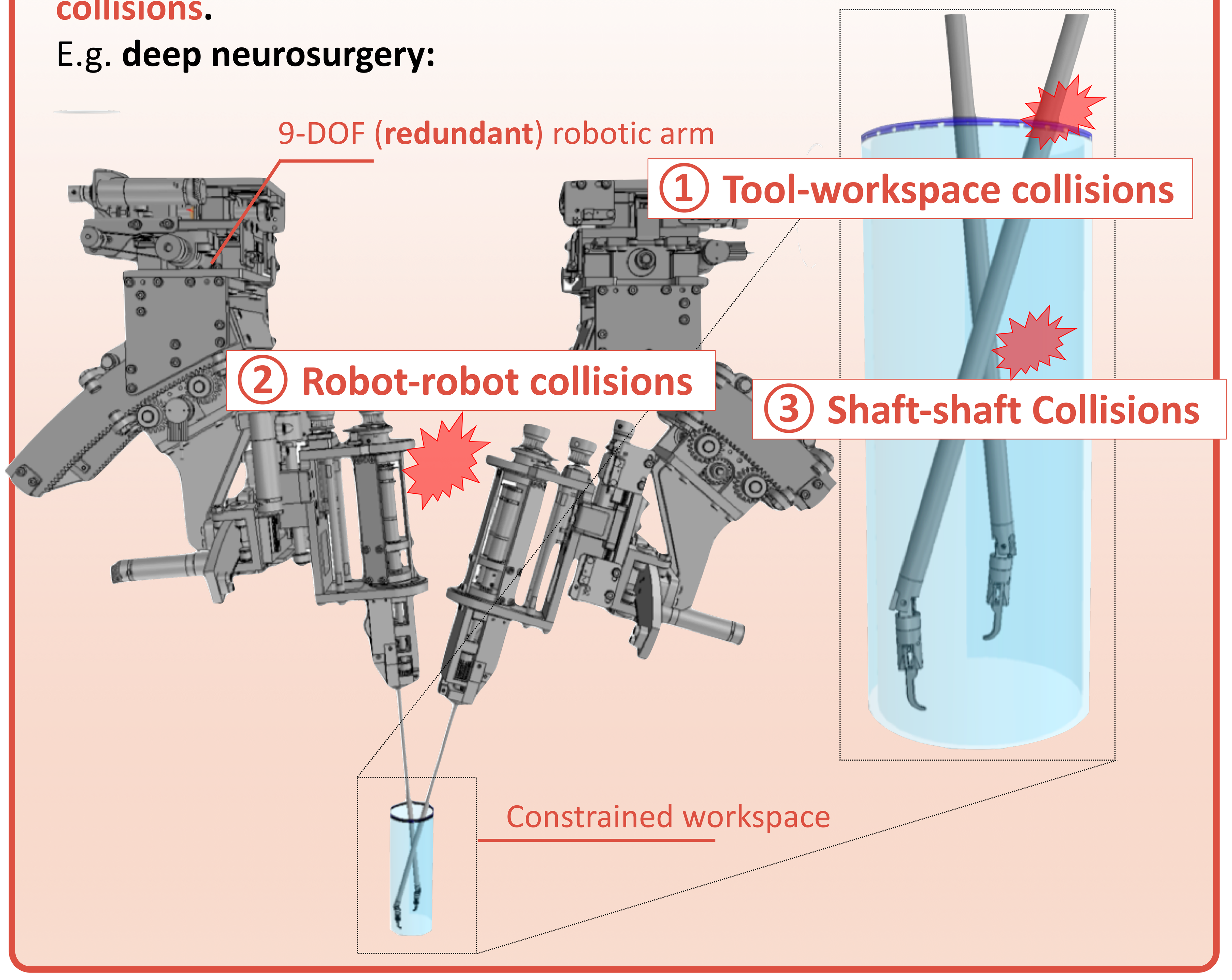
Motivation: Deep brain vessel anastomosis



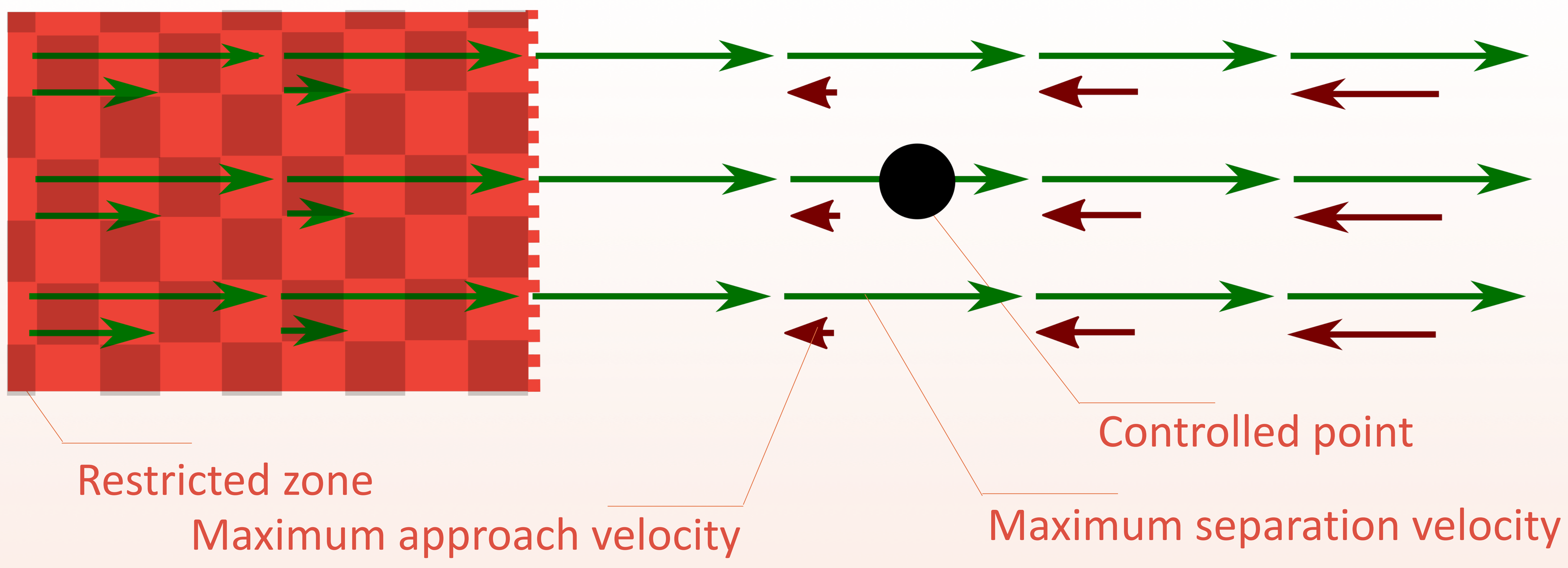
Submillimeter accuracy is required in a **highly constrained workspace**.

② Objective

Our goal is to develop an active constraints framework applied to deep and narrow regions. We aim for a **real-time algorithm to prevent collisions**.
E.g. **deep neurosurgery:**



③ Proposed methodology



Method requires a **distance function** and a **distance Jacobian** between pairs of primitives.

Constrained Optimization

$$\min_{\dot{\boldsymbol{q}}} \| \boldsymbol{J}\dot{\boldsymbol{q}} + \eta\tilde{\boldsymbol{x}} \|_1$$
$$\text{s.t.} \boldsymbol{W}\dot{\boldsymbol{q}} \leq \boldsymbol{w}$$

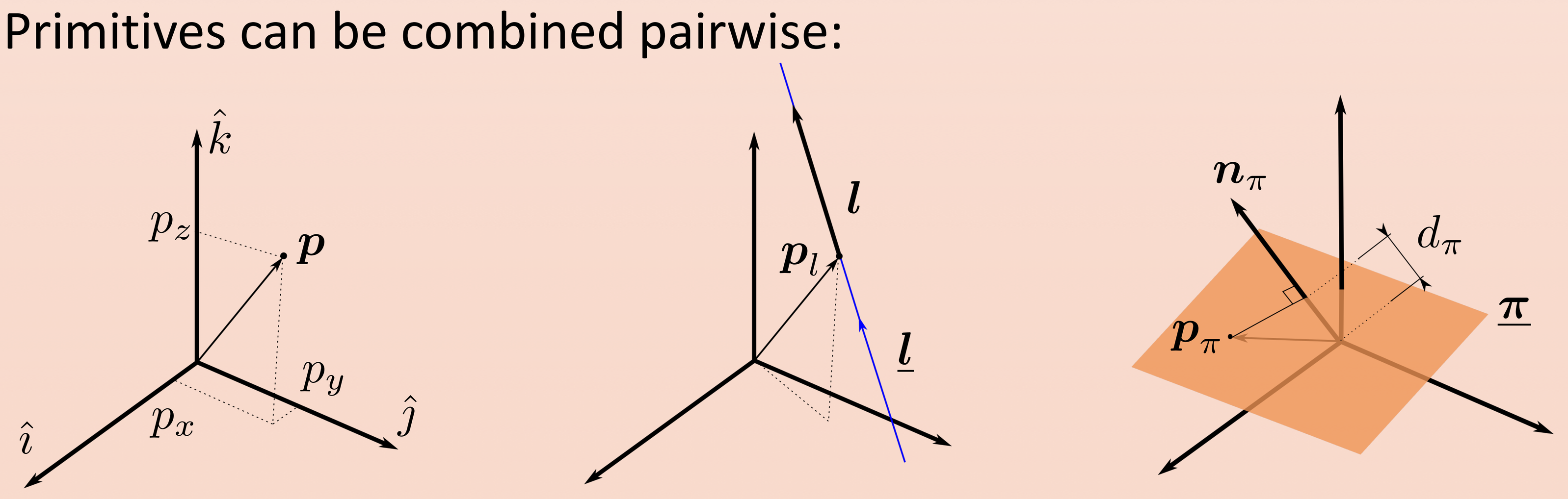
Distance Jacobian

$$\dot{d}(t) = \underbrace{\frac{\partial \left(d(t)\right)}{\partial \boldsymbol{q}}}_{\boldsymbol{J}_d} \dot{\boldsymbol{q}}$$

Linear Constraint

$$-\boldsymbol{J}_d\dot{\boldsymbol{q}} \leq \eta_d\tilde{d}(t)$$

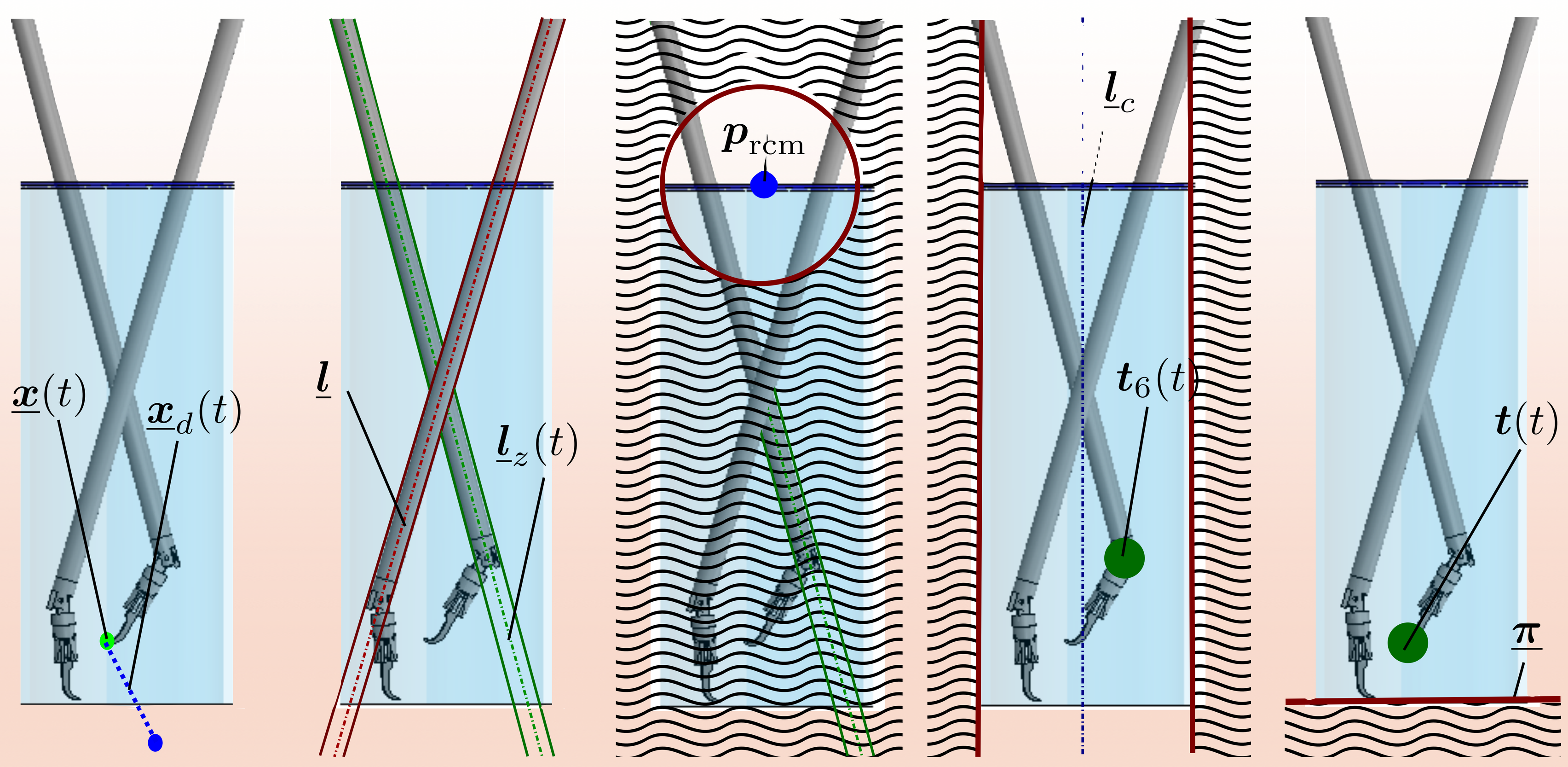
Primitives can be combined pairwise:



$$\boldsymbol{p} = p_x\hat{\imath} + p_y\hat{\jmath} + p_z\hat{k}$$

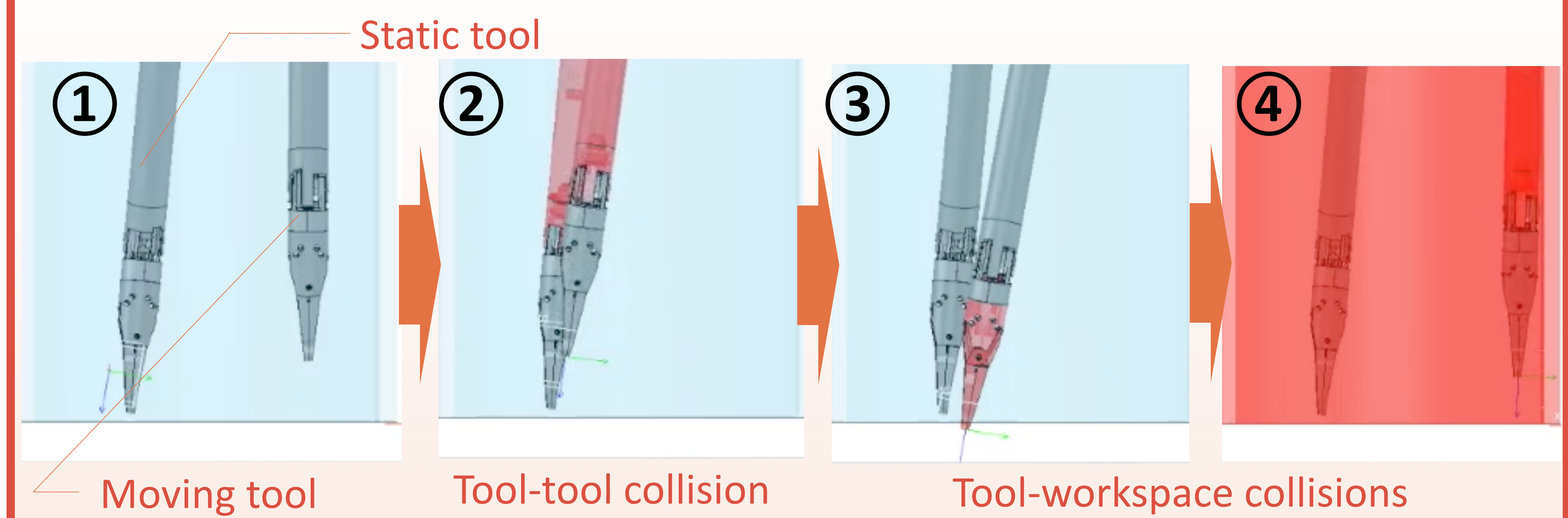
$$\underline{\boldsymbol{l}} = \boldsymbol{l} + \varepsilon\boldsymbol{m}$$
$$\boldsymbol{m} = \boldsymbol{p}_l \times \boldsymbol{l}$$

$$\underline{\boldsymbol{\pi}} = \boldsymbol{n}_\pi + \varepsilon d_\pi$$
$$d_\pi = \langle \boldsymbol{p}_\pi, \boldsymbol{n}_\pi \rangle$$

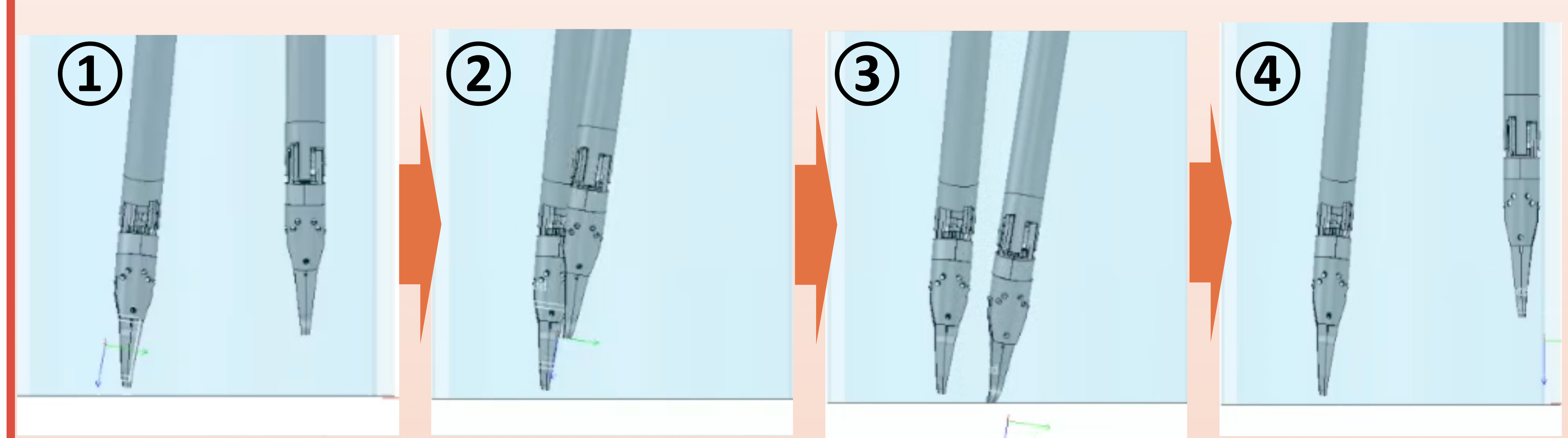


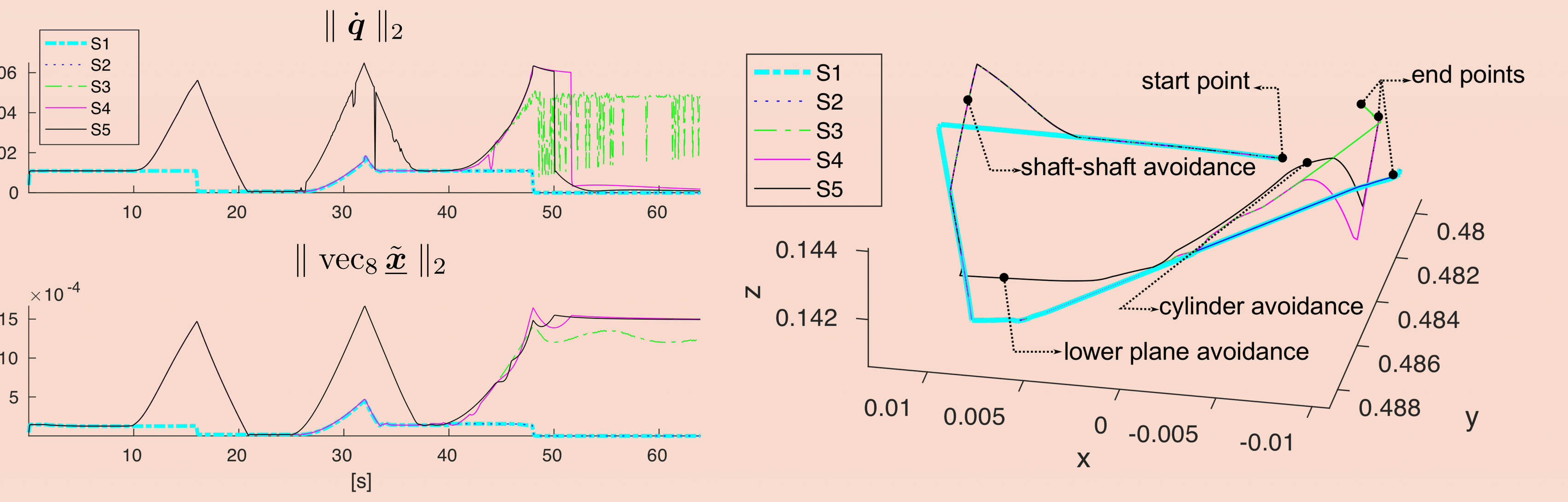
④ Simulations

No active constraints



With active constraints





⑤ Conclusion

Primitives modelled **complex interactions** between robots and workspace, preventing collisions with **smooth velocities** in **real-time**.

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