Tac-Man: Tactile-Informed Prior-Free Manipulation of Articulated Objects

Paper | Project page

IEEE Transactions on Robotics (T-RO) Volume 41

Oral information: in Room 101, Wednesday, October 22, 2025, 15:20–15:25.

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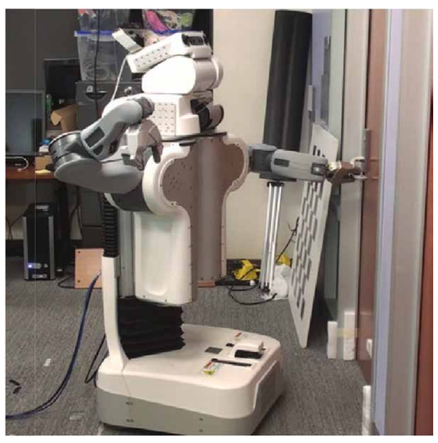
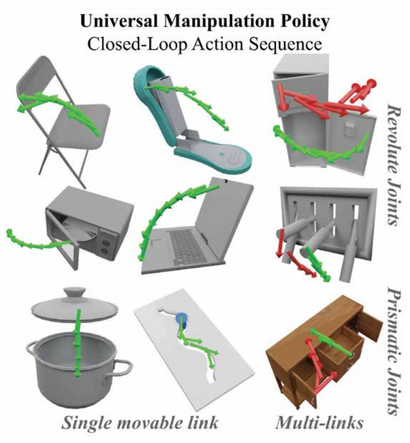
Are **kinematic priors** necessary for manipulating an articulated object?



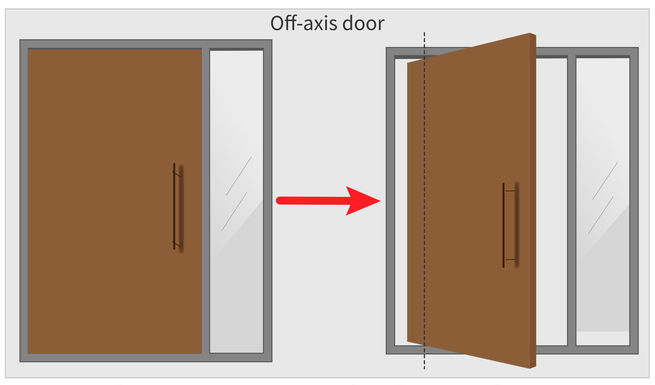
Explicit kinematics for planning
[Schulman, *et al.,* IJRR 2014]



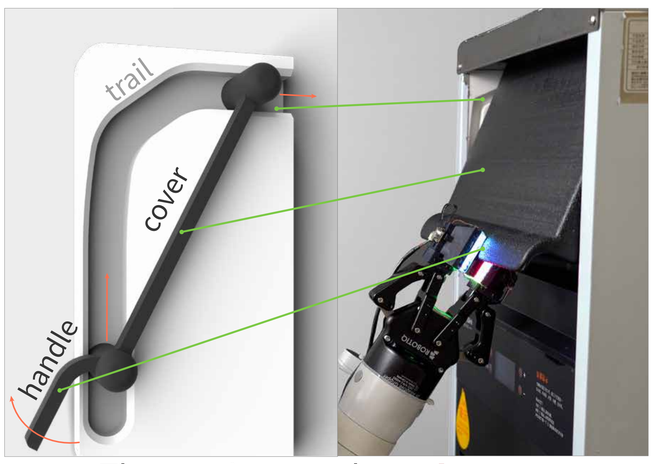
Implicit kinematics for learning
[Xu, *et al*., RA-L 2022]

Although effective, these priors can be difficult to obtain precisely.

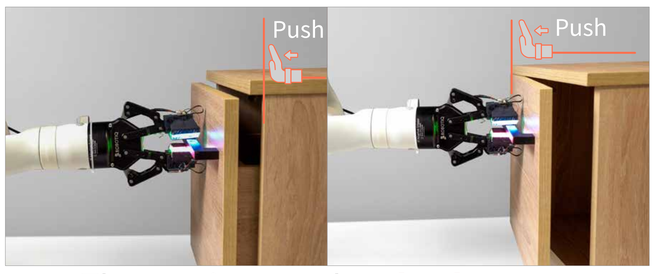
These priors can be **ambiguous**.
Different mechanism can share the same appearance.



These priors can be **imperfect**.
Even with the correct articulation type, parameter estimation is prone to errors.



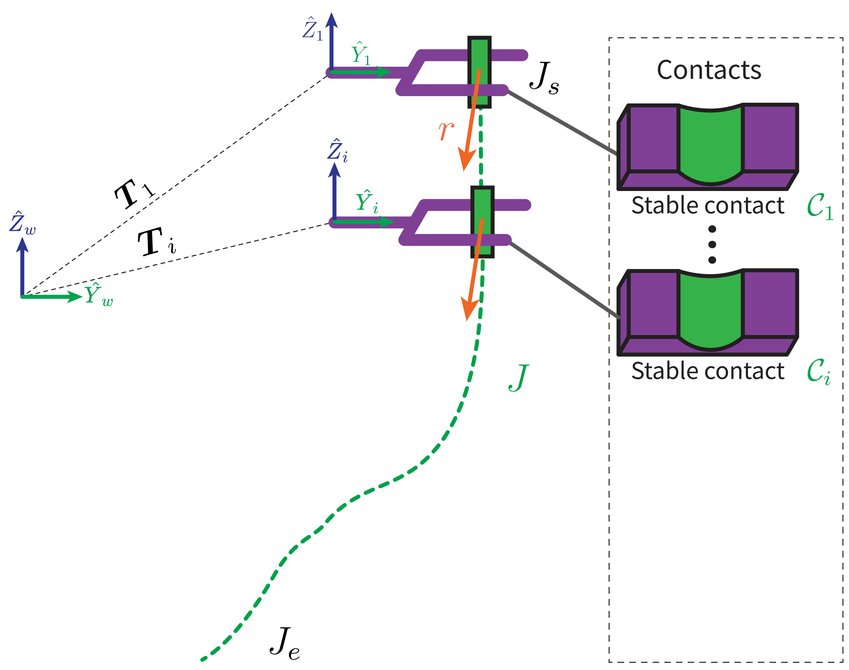
These priors can be **unknown**.
Some complex screw motions are hard to model and to capture in datasets.



These priors can be **obsolescent**.
Perturbations can render the priors unsuitable for the current scenario.

Contact regulation is all you need! A two-stage tactile-informed policy:

Execution stage



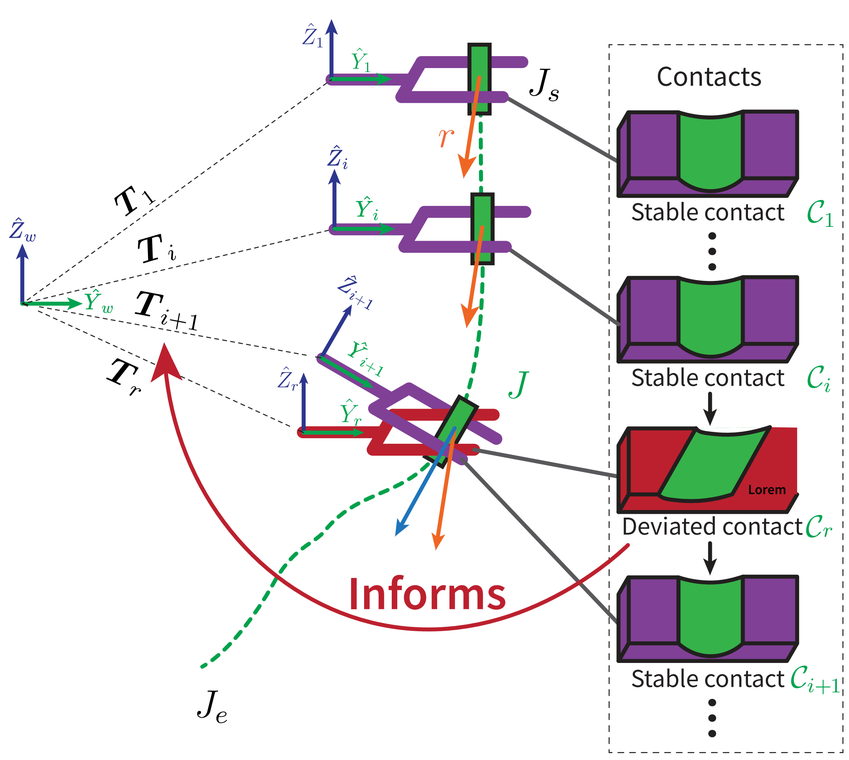
For any articulation J, execute along a preliminary direction r when the contact $\mathcal{C}_i$ is **stable**:

$$\underset{t}{\text{maximize}} \quad t$$

$$\text{subject to} \quad f_e(f_c(\boldsymbol{T}_i\boldsymbol{T}_r^i, J), \mathcal{C}_0) \le \boldsymbol{e}, \text{ Material strength}$$
$$f_s(f_c(\boldsymbol{T}_i\boldsymbol{T}_r^i, J), \mathcal{C}_0) \le s, \text{ Non-slip}$$
$$f_d(f_c(\boldsymbol{T}_i\boldsymbol{T}_r^i, J), \mathcal{C}_1) \le d. \text{ Contact deviation}$$

Stable contact constraint

Recovery stage



Until the contact violates the stable contact constraint, the contact deviation informs the necessary adjustments to reestablish stable contact:

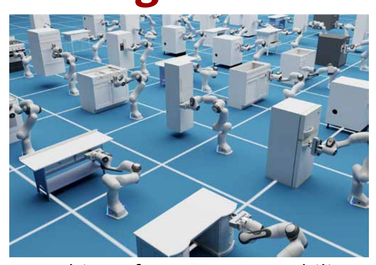
$$\boldsymbol{T}_{i+1}^r = \underset{\boldsymbol{T}_{i+1}^r \in SE(3)}{\arg\min} \sum_{(\boldsymbol{u},\boldsymbol{v}) \in \mathcal{K}_{1r}} \|\boldsymbol{T}_{i+1}^r \boldsymbol{u} - \boldsymbol{v}\|_2$$

$$\mathcal{K}_{1r} = \{(\boldsymbol{u}, \boldsymbol{v}) \mid \boldsymbol{u} \in \mathcal{C}_1, \boldsymbol{v} \in \mathcal{C}_r\}$$

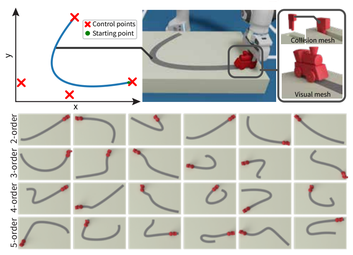
Through the iterative process, the manipulation can be completed.

Near-perfect results:

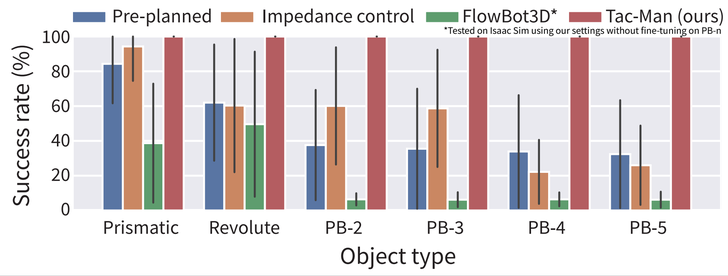
Large-scale simulation study



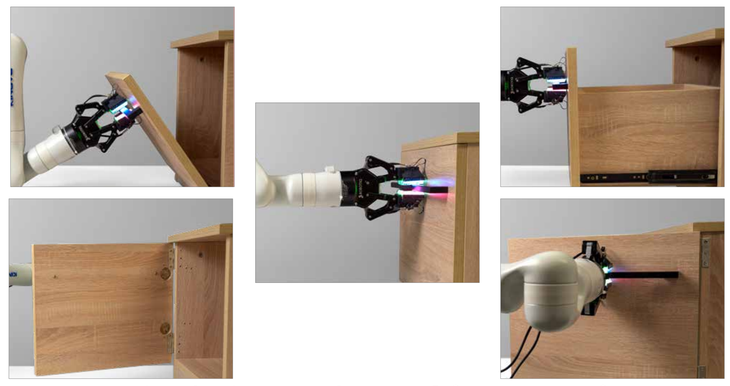
50 objects from PartNet-Mobility



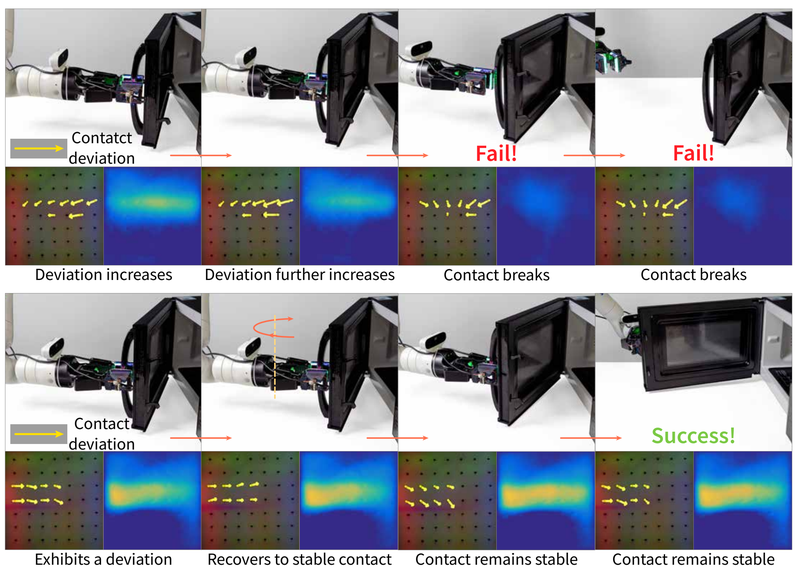
100 randomly-generated curves



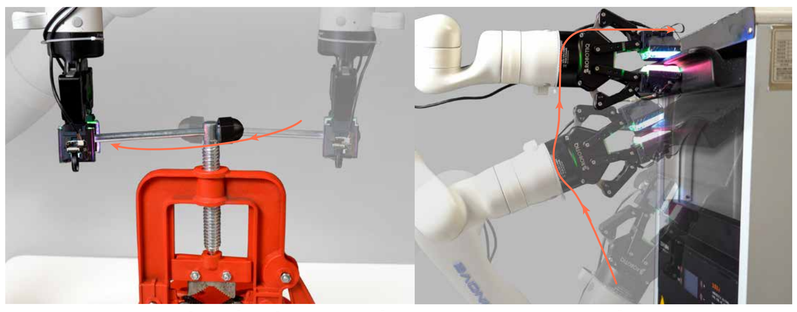
Real-world validations



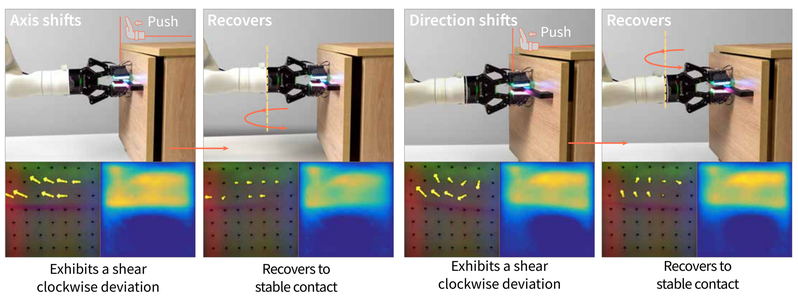
Manipulation under **ambiguous priors**



Manipulation under **imperfect priors**



Manipulation under **unknown priors**



Manipulation under **obsolescent priors**