Current-Based Impedance Control for Interacting with Mobile Manipulators

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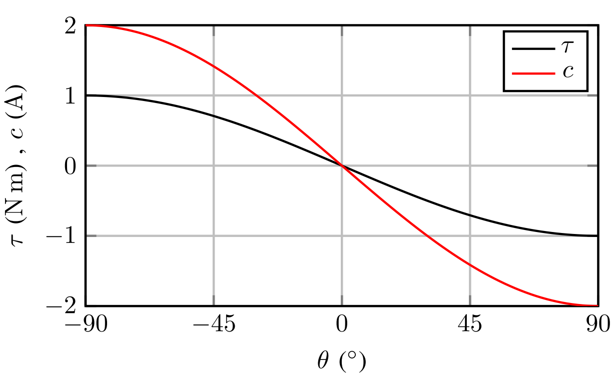
Two common methods for safe interaction, admittance, and impedance control, require force or torque (FT) sensors, often absent in lower-cost or lightweight robots.
This paper presents an adaption of impedance control that can be used on **current-controlled robots without FT sensors**. To this end, we present a calibration method that enables estimation of the actuators' current/torque ratios and frictions and can **handle model errors**.
We show its application for compliant control of a mobile manipulator through two operational modes.

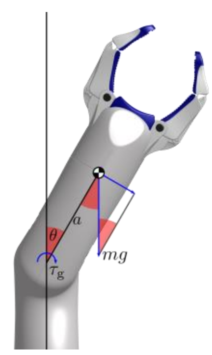
Paper

Videos & Code

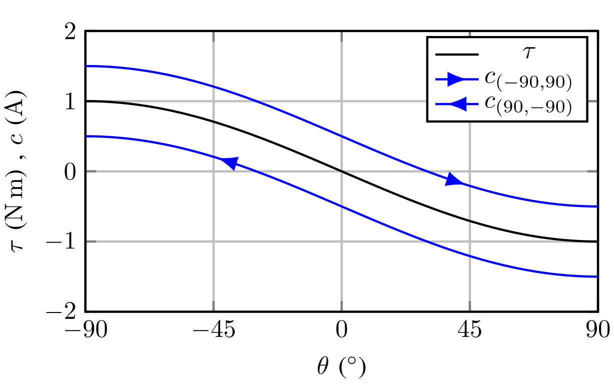
Method

A **calibration method** is designed to enable the estimation of the actuators' current/torque ratios r and frictions l without FT sensors. Each joint is moved individually, with constant velocity, while the actuator current c is measured (N measurements) and compared with the model-based actuator torque τ:



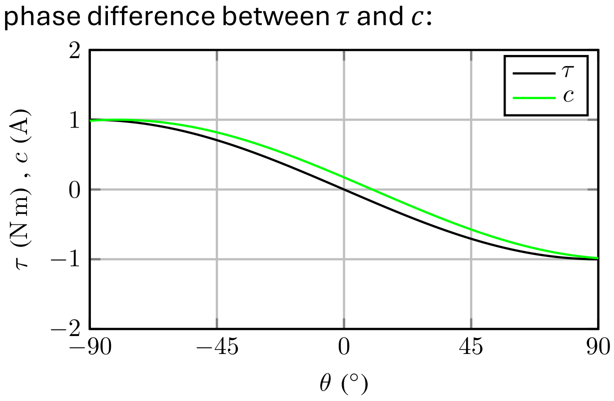


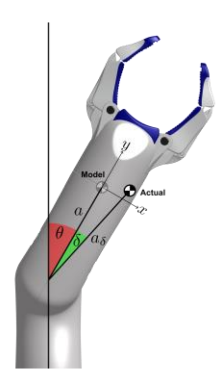
For a **joint with friction**, the current is shifted up relative to τ for a movement in one direction, while it is shifted down for the opposite direction. This occurs because friction opposes upward link movement initially, while friction hinders joint acceleration during downward movement:



$$r^*, l^* = \underset{r,l}{\operatorname{argmin}} \sum_{i=1}^{N} (c_i - (r\tau_i + l))^2$$

One can estimate r and l by solving a minimization problem. However, the discrepancy in the angle between the model and the actual robot results in a phase difference between τ and c:



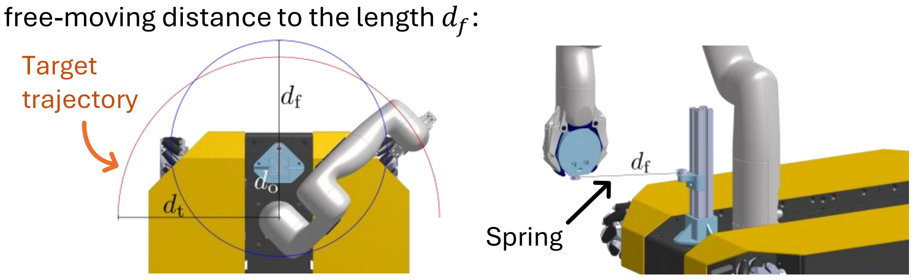


$$s^*, \delta^* = \underset{s,\delta}{\operatorname{argmin}} \sum_{i=1}^{N} (c_i - s\sin(\theta_i + \delta))^2$$

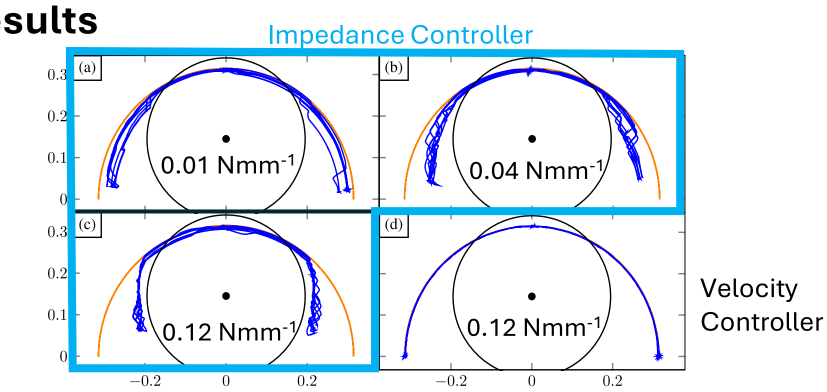
To address the **model errors**, data can be recorded in two directions and averaged, effectively canceling out the impact of friction. Subsequently, the error angle between the model and the robot can be estimated by solving the minimization problem outlined above. This estimated model error can then be applied to refine and correct the model.

Experiment

We evaluate the compliance of the adapted impedance controller by simulating interaction using springs with varying stiffness. A setup is arranged where the end effector (EE) is attached to a spring, limiting its free-moving distance to the length d_f:



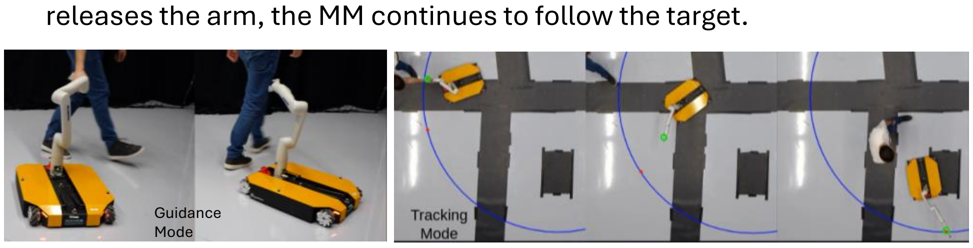
Results



EE following the target trajectory for varying spring stiffness:
(a) Spring is weaker and thus more compliant than the controller
(b) Spring stiffness is similar to the controller stiffness
(c) Spring stiffness is larger, the EE staying closer to the black circle
(d) Velocity controller with 1 mm tracking precision but lacks compliance (compliant controller achieves a precision of ca. 5 mm).

Operational Modes for Mobile Manipulator (MM)

- Guidance Mode: The target of the EE is fixed in the base's frame, allowing humans to guide the MM by interacting with the arm.
- Tracking Mode: The target is fixed in the world frame. Once the human releases the arm, the MM continues to follow the target.



Conclusion & Future Work

We presented a holistic approach addressing **compliance for mobile manipulators using off-the-shelf manipulators and wheeled mobile bases**:

- A calibration method that enables the application of impedance control on current-controlled manipulators, we showed its consistency
- Two operational modes for interacting with mobile manipulators

Future work may demonstrate the calibration method's correctness on an arm with force/torque sensors and apply the calibration method to a current controlled base.

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