Effects of Compliance in Parallel to Actuators on Grasping and Manipulation in Robotic Hands

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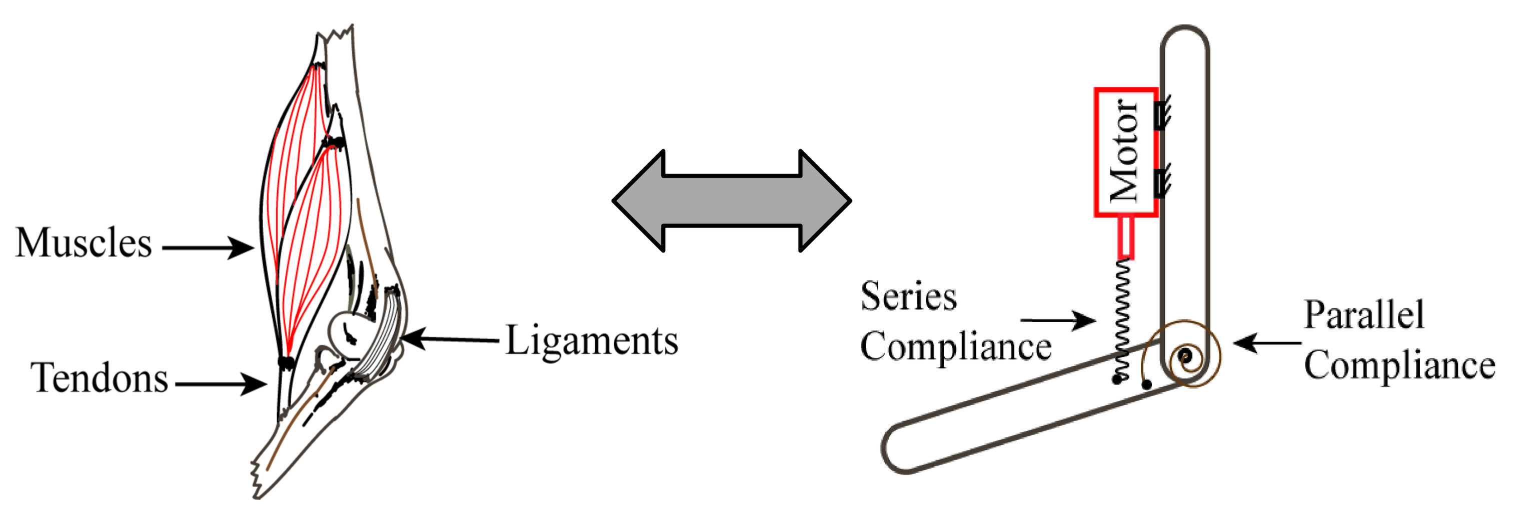
Objective

Parallel compliance results from elastic elements arranged alongside actuators, and its effects on robotic hands requires in-depth analysis.

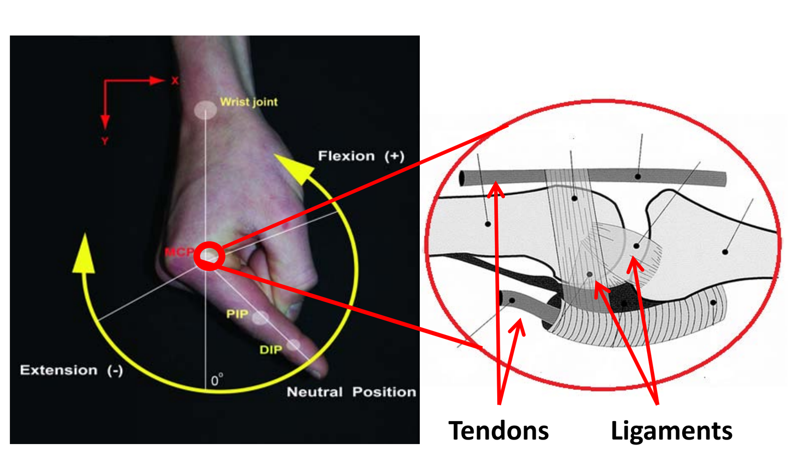
- Series compliance in robotic joints has been studied and implemented extensively (SEAs, VSAs etc.).
- Parallel compliance has been implemented as a return mechanism in a few robotic hands but its effects on system dynamics have not been thoroughly analyzed.
- We theoretically analyze the effects of parallel compliance on robotic joints and validate our findings with experiments on a gripper testbed.

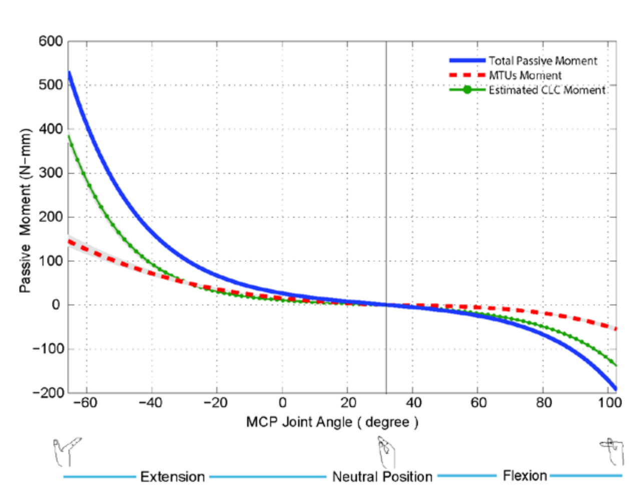
Parallel Compliance in Human Joints

- Humans exploit various arrangements of compliance to achieve robust performance and graceful manipulation. Tendons provide series compliance with respect to the muscles while ligaments and joint capsules provide parallel compliance at the joint.



- Studies of the metacarpal (MCP) joint show that parallel compliance due to ligaments and joint capsules has a dominant effect on the net passive moment [1].

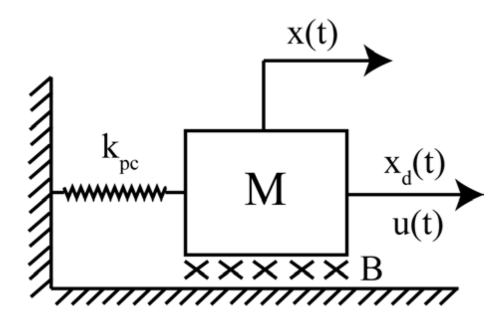




[1] P.H. Kuo and A. Deshpande 2012

Parallel Compliance in Robotic Joints

- We modeled a generic robotic joint With compliance in parallel to the actuator.



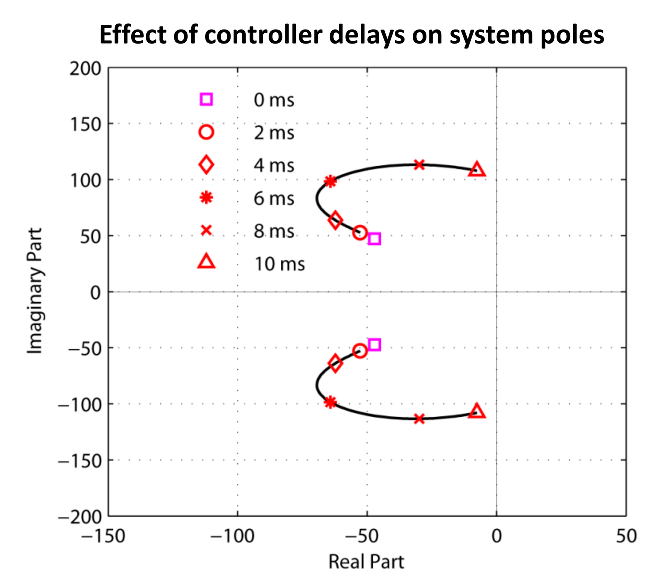
- We implemented impedance control at the joint, as it is commonly used for grasping and manipulation tasks,

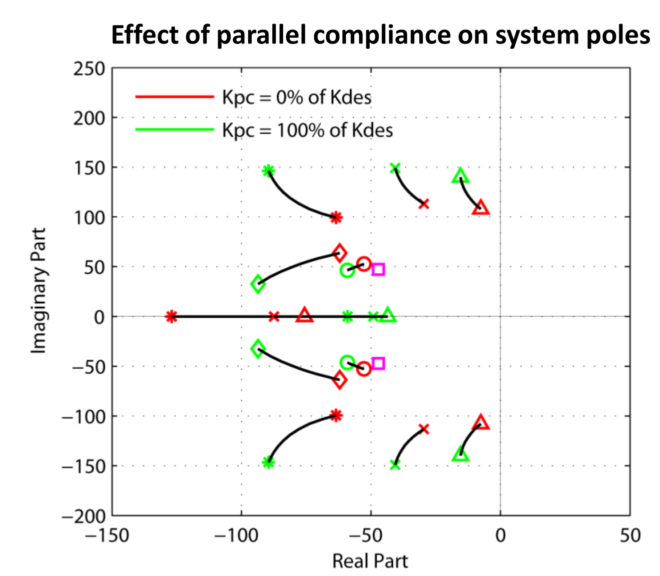
$$u = k_p(x_d - x) - k_d\dot{x} + k_{pc}x_d$$

- Controller is designed such that total closed-loop stiffness is the same in presence or absence of parallel compliance,

$$k_{des} = k_p + k_{pc}$$

- Feedback delays in the closed loop system modeled.



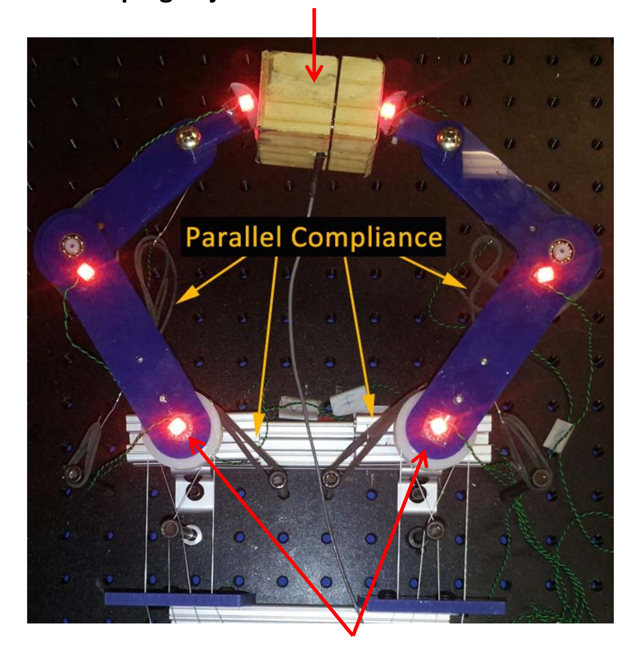


Adding parallel compliance pushes system poles toward more stable regions in the presence of controller delays.

Experimental Setup

- Light-weight 2N tendon-driven robotic gripper testbed designed.
- Joint angles estimated using real-time motion capture system.
- Parallel compliance of different stiffness values evaluated.
- Object with embedded force sensor designed for grasping and manipulation experiments.

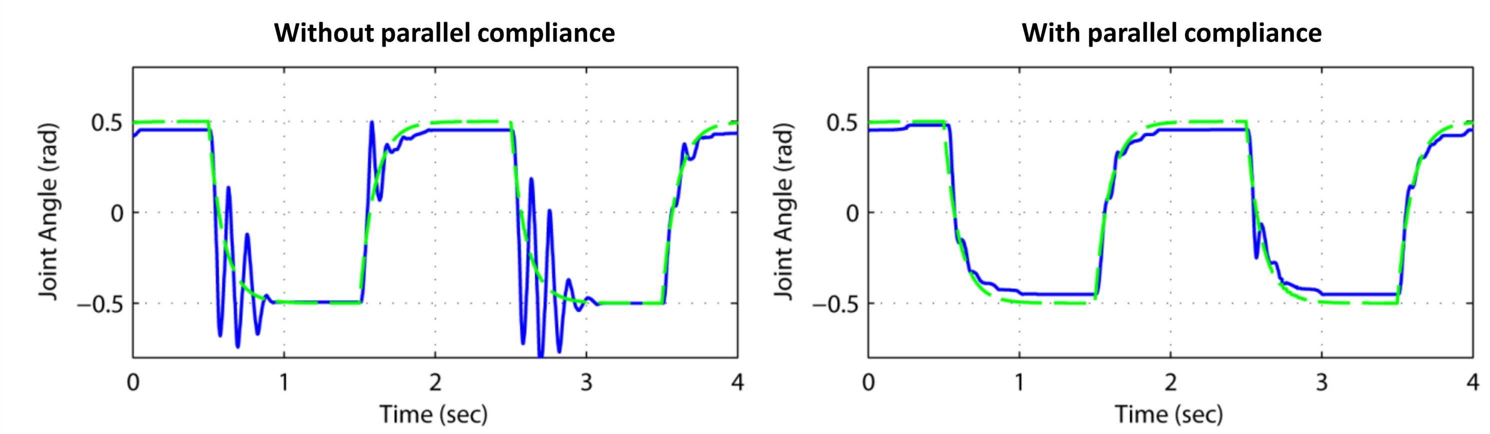
Grasping object with embedded force sensor



Motion Capture markers

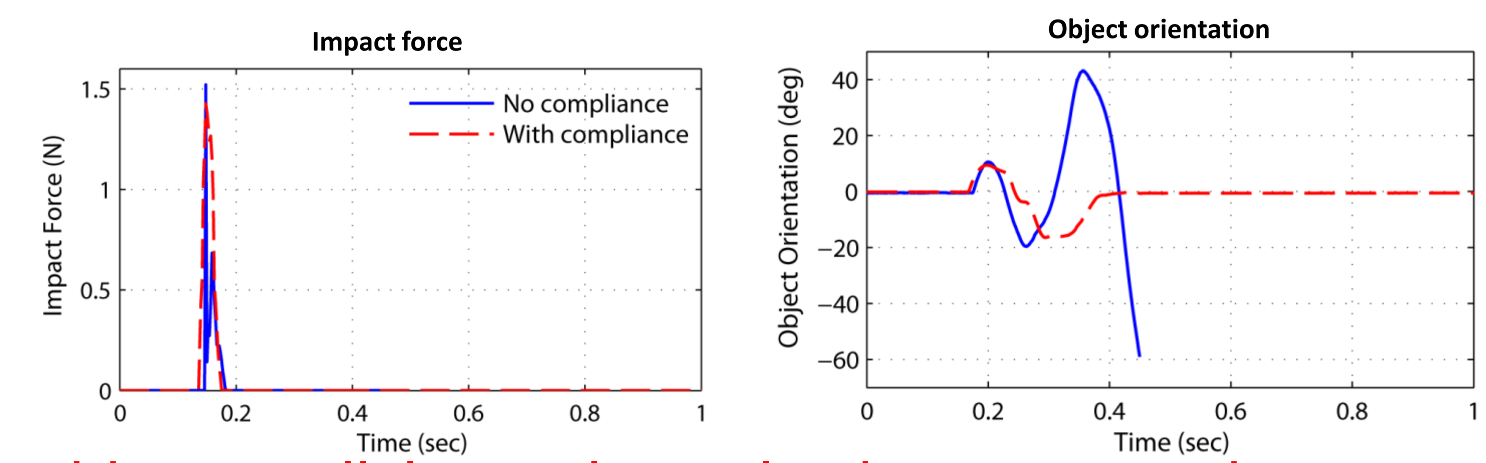
Results

- Trajectory tracking results – A single joint with and without parallel compliance followed a desired trajectory.



Adding parallel compliance leads to more stable trajectory tracking performance.

- Impact testing results – Impacts were applied as the gripper maintained constant grasp force on an object.



Adding parallel compliance leads to improved impact stability.

Discussion

- Adding parallel compliance to robotic joints improves stability and robustness in the presence of impacts and controller delays.
- Further analysis on the effects of human-like nonlinear parallel compliance can help in achieving the goal of designing robotic hands that match human-like grasping and manipulation capabilities.

Acknowledgements

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