Superposition of Mechanical Impedance

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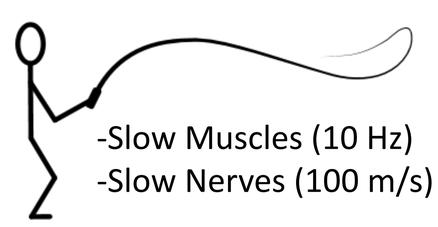
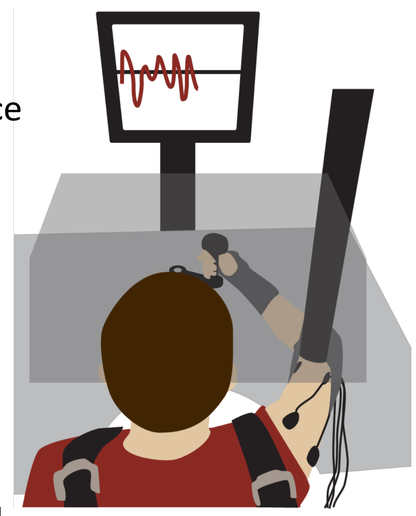
Motivation

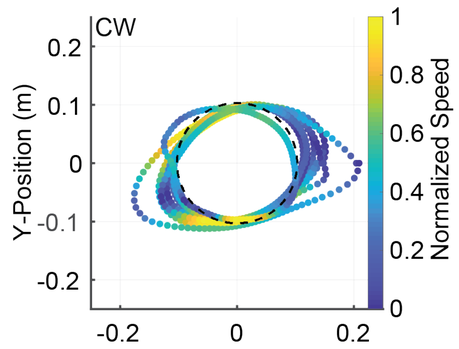
- Human physical interaction with complex dynamic objects is superior to contemporary robots despite markedly inferior resources (neuro-mechanics).
- How can high degree-of-freedom modern robotic systems be controlled, e.g. humanoids?
- Interaction is difficult, it often involves closed chain manipulation and transitions in and out of contact.
- Computational complexity limits real-time control using optimization-based methods.

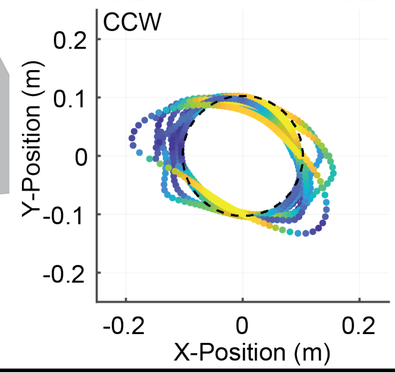


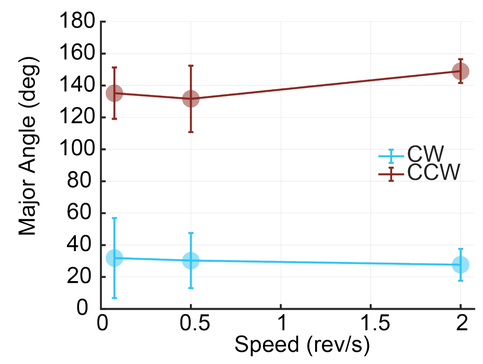
Evidence for Human Impedance Control

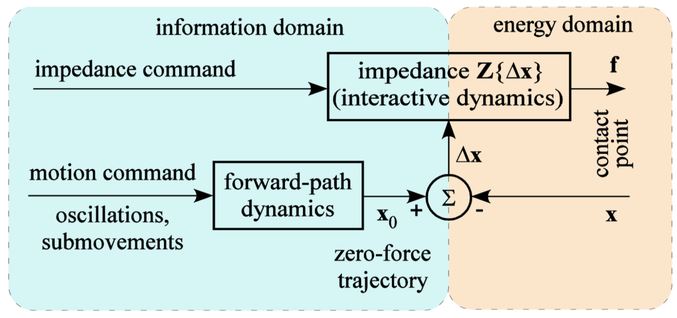
- In a crank turning task, subjects exhibited systematic and significant errors despite availability of feedback.
- Consistent with use of low arm mechanical impedance in order to comply with the circular constraint.
- Subjects generated an approximately-elliptical underlying motion that exhibited a speed-curvature relation resembling that reported in unconstrained motion.
- Differences between clockwise (CW) and counter-clockwise (CCW) turning were observed in the execution of the same constrained-motion task.
- A model that accounted for the anisotropy of skeletal inertia and neuro-muscular impedance was sufficient to reproduce these results.







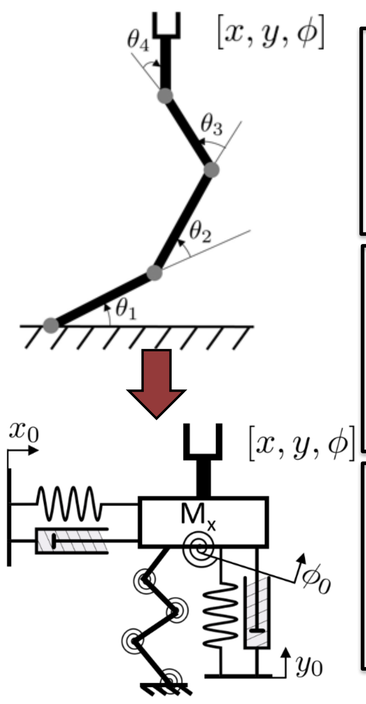


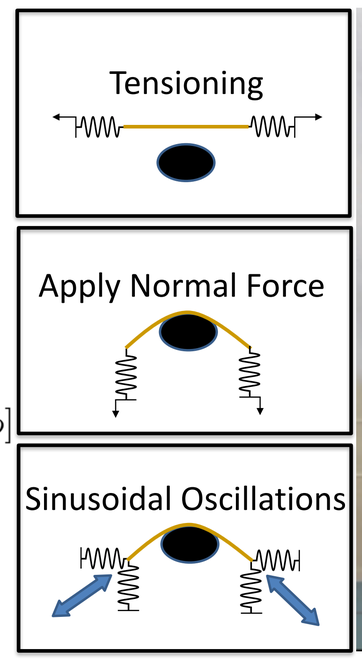


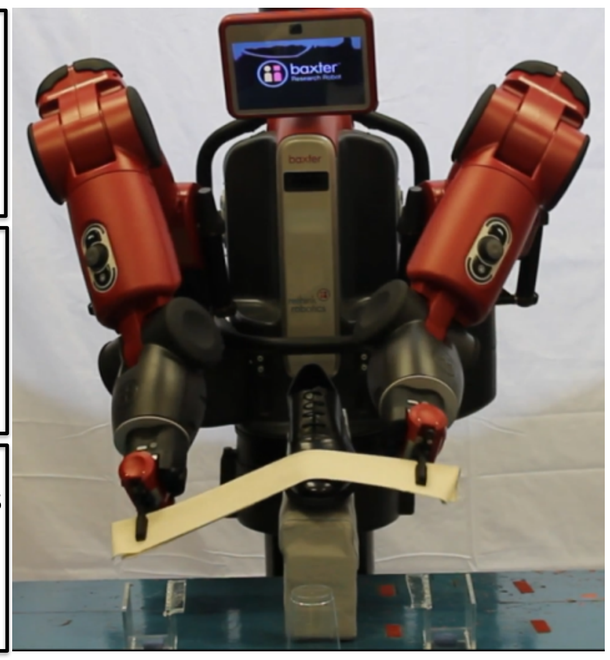
Impedance Superposition in Robots

Impedance control facilitates programming dynamic interactive behavior on robots and enables scale-up to complex tasks.

- Complex interactive tasks can be broken down into sub-tasks.
- A controller based on dynamic primitives can be implemented for each sub-task, and these controllers can be linearly superimposed.
- Controller compliance can tackle poorly modeled tasks in a manner similar to humans.
- Seamless transition into and out of contact, along with operation into and out of singularity.
- In highly redundant manipulation scenarios, the complexity of the problem scales as the number of impedance sub-tasks, rather than the total number of robot joints. This enables intelligent scale-up.







Redundancy Resolution in Contact

Limitations of impedance superposition:

- Task impedances may conflict with each other
- No priority assignment to sub-tasks

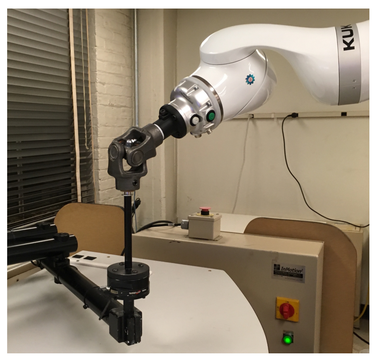
One solution: nullspace projection:

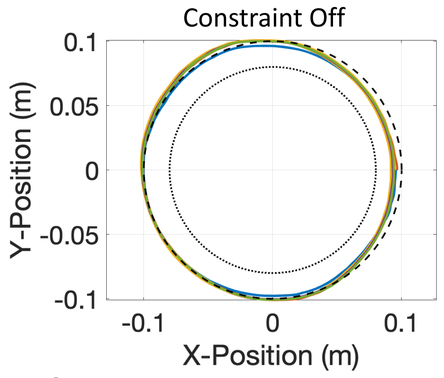
- Use joint forces not needed to balance end-effector impedances
- Challenge: select an appropriate weighting matrix for Jacobian inversion
- Study projector effects on forceful interaction

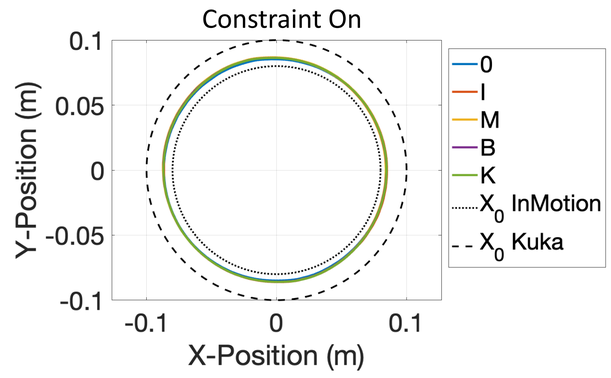
$$\boldsymbol{\tau} = \boldsymbol{J}^T\left[\boldsymbol{K}_x(\boldsymbol{x}_0 - \boldsymbol{x}) + \boldsymbol{B}_x(\dot{\boldsymbol{x}} - \boldsymbol{x})\right] + \boldsymbol{N}\left[\boldsymbol{K}_q(\boldsymbol{q}_0 - \boldsymbol{q}) - \boldsymbol{B}_q\dot{\boldsymbol{q}}\right]$$

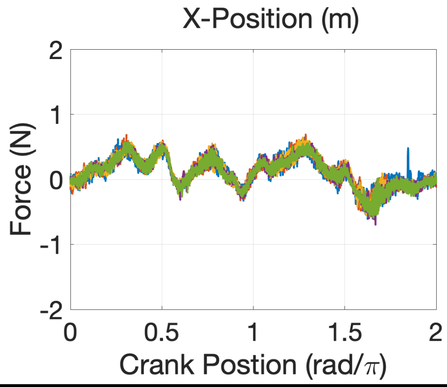
$$\boldsymbol{N} = \left(\boldsymbol{I} - \boldsymbol{J}^T(\boldsymbol{J}^{\#})^T\right)$$

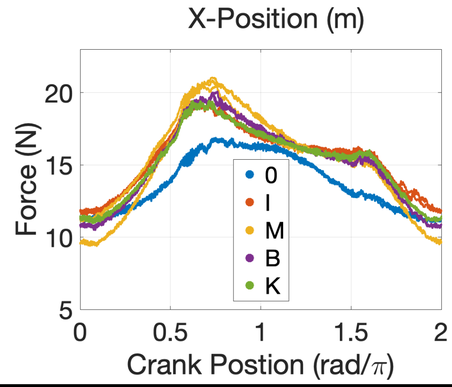
$$\boldsymbol{J}^{\#} = \boldsymbol{W}^{-1}\boldsymbol{J}^T(\boldsymbol{J}\boldsymbol{W}^{-1}\boldsymbol{J}^T)^{-1}$$











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