Contact-aware Control of Dynamic Manipulation
PI: Michael Posa, University of Pennsylvania
Award No. 1830218, 9/2018-9/2021

Challenge

Frictional contact is the fundamental mechanism of robot manipulation, but robots are **afraid of dynamic interaction** with the world.
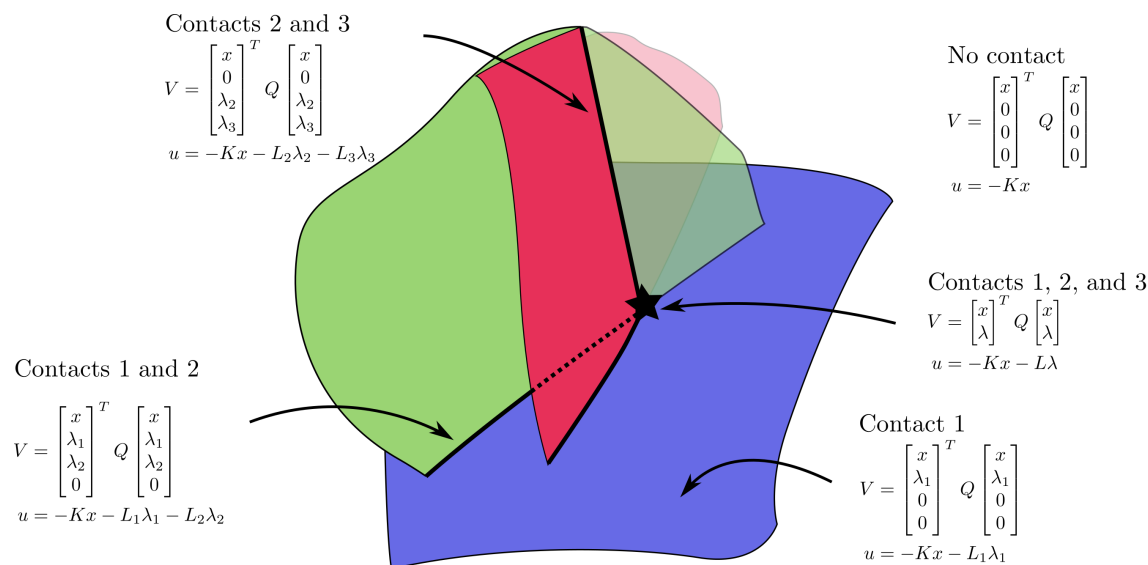
Solution

- Model-based and data-driven approaches to modeling multi-contact
- Contact-aware control synthesis leveraging tactile feedback.
- Algorithms that leverage non-smooth structure in control and learning dramatically improve scalability and effectiveness.

Scientific Impact

Reformulations of quasi-static motion, simultaneous impacts, and control design with tactile feedback can be widely leveraged across robotics.

Broader Impact

- Effective robots require high-speed interaction that is effective and safe around humans.
- Mentorship of local, Philadelphia area high-school students and community outreach.

Contacts 2 and 3
$$V = \begin{bmatrix} x \\ 0 \\ \lambda_2 \\ \lambda_3 \end{bmatrix}^T Q \begin{bmatrix} x \\ 0 \\ \lambda_2 \\ \lambda_3 \end{bmatrix}$$
$$u = -Kx - L_2\lambda_2 - L_3\lambda_3$$

No contact
$$V = \begin{bmatrix} x \\ 0 \\ 0 \\ 0 \end{bmatrix}^T Q \begin{bmatrix} x \\ 0 \\ 0 \\ 0 \end{bmatrix}$$
$$u = -Kx$$

Contacts 1, 2, and 3
$$V = \begin{bmatrix} x \\ \lambda \end{bmatrix}^T Q \begin{bmatrix} x \\ \lambda \end{bmatrix}$$
$$u = -Kx - L\lambda$$

Contacts 1 and 2
$$V = \begin{bmatrix} x \\ \lambda_1 \\ \lambda_2 \\ 0 \end{bmatrix}^T Q \begin{bmatrix} x \\ \lambda_1 \\ \lambda_2 \\ 0 \end{bmatrix}$$
$$u = -Kx - L_1\lambda_1 - L_2\lambda_2$$

Contact 1
$$V = \begin{bmatrix} x \\ \lambda_1 \\ 0 \\ 0 \end{bmatrix}^T Q \begin{bmatrix} x \\ \lambda_1 \\ 0 \\ 0 \end{bmatrix}$$
$$u = -Kx - L_1\lambda_1$$

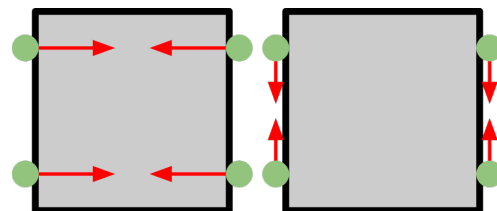# Contact-aware Control of Dynamic Manipulation
PI: Michael Posa, University of Pennsylvania
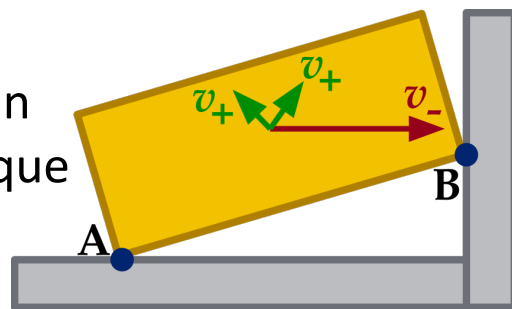## Award No. 1830218, 9/2018-9/2021

Quasi-static Modeling

- Introduced linear complementarity model to unify pushing, grasping, and jamming.

Simultaneous Impacts

- Multiple impacts ubiquitous in robotics, but lead to non-unique outcomes/high sensitivity.
- Created differential inclusion to capture set of possible post-impact states

Learning Contact Dynamics

- Preliminary work embeds discontinuities into learned networks for dramatically improved data efficiency

Contact-aware Control

- **Provably stable** control policies that leverage tactile feedback on force λ

$$u = -Kx - L\lambda, \qquad V = \begin{bmatrix} x \\ \lambda \end{bmatrix}^T Q \begin{bmatrix} x \\ \lambda \end{bmatrix}$$

- By linearizing *smooth* part of dynamics, but leaving contact discontinuities, synthesis via bilinear matrix inequalities (BMIs)
- Controller and Lyapunov function mirror the non-smooth dynamics, but are non-combinatoric

Multi-contact Model Predictive Control

Ongoing work to find approximate but real-time solutions to MPC in contact-rich settings.

Aydinoglu, Preciado, **P**. Contact-Aware Controller Design for Complementarity Systems. ICRA, 2020.
Halm and **P**. Modeling and Analysis of Non-unique Behaviors in Multiple Frictional Impacts. RSS, 2019.
Halm and **P.** A Quasi-static Model and Simulation Approach for Pushing, Grasping, and Jamming. WAFR, 2018.