Provably Safe and Efficient Motion Planning with Uncertain Human Dynamics

Shen Li, Nadia Figueroa, Ankit Shah, Julie A. Shah

https://safe-dressing.github.io/

Motivations

- Ensure human physical safety,
- without unnecessarily impacting task efficiency.

Contributions

- Planner with probabilistic safety guarantee.
- Define safety as collision avoidance OR safe impact during collisions.

Human dynamic model (human pos, vel)

- $p_H^{t+1} = p_H^t + g(p_H^t, p_R^t)$
- $v_H^{t+1} = \frac{1}{h}(p_H^{t+1} - p_H^t)$

Assumption 1: Human is deterministic

Model is learned via *GP*

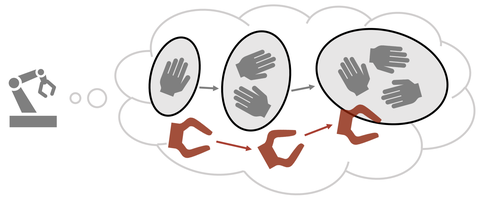
Uncertainty is captured by *confidence intervals*

Assumption 3: Human is "smooth"

Ellipsoidal predictions for human (pos, vel)

Future human ∈ ellipsoids

MPC that guarantees human physical safety during interaction



Assumption 2: Recovery controller

Ensure collision avoidance or safe impact regarding all ellipsoids

Collision avoidance constraint over:
- A robot pos
- A human pos

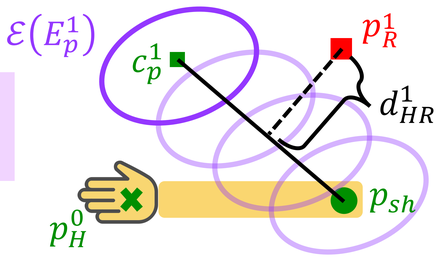
Safe impact constraints over:
- A robot vel
- A human vel

Collision avoidance constraint over:
- A robot pos
- An ellipsoid for human pos

Safe impact constraints over:
- A robot vel
- An ellipsoid for human vel

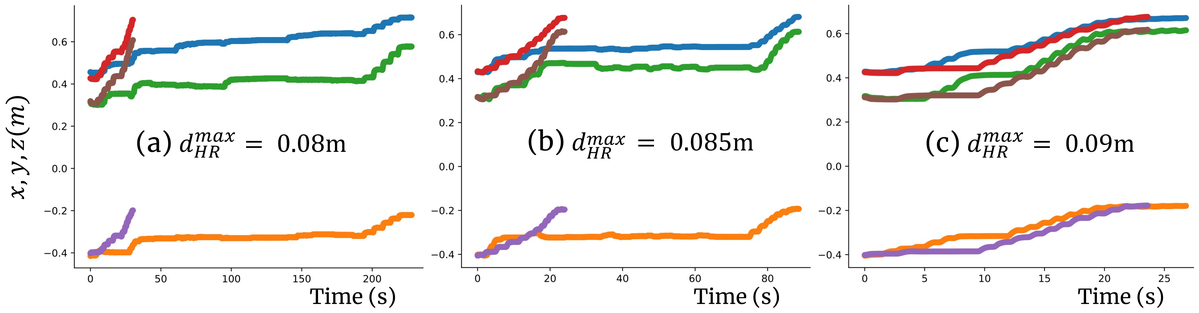
OR

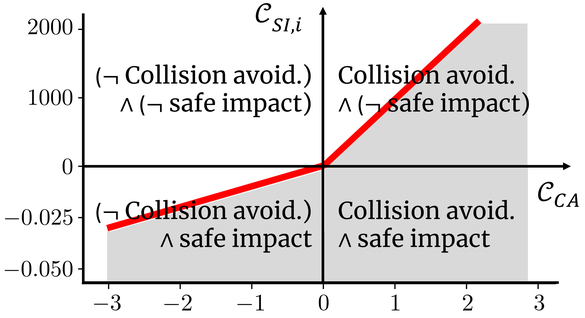
1. Real-world robot-assisted dressing:



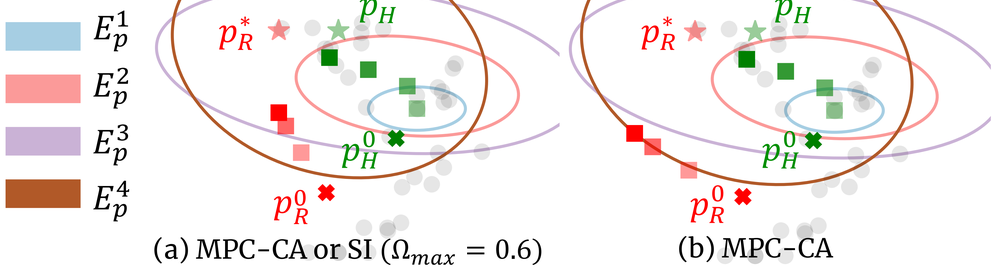
MPC-CA or SI ($\Omega_{max} = 1$): x y z

MPC-CA: x y z





2. Simulated 2D goal-reaching:



(a) MPC-CA or SI ($\Omega_{max} = 0.6$) (b) MPC-CA