Safe Learning in Co-robots--Theory, Experiments and Education

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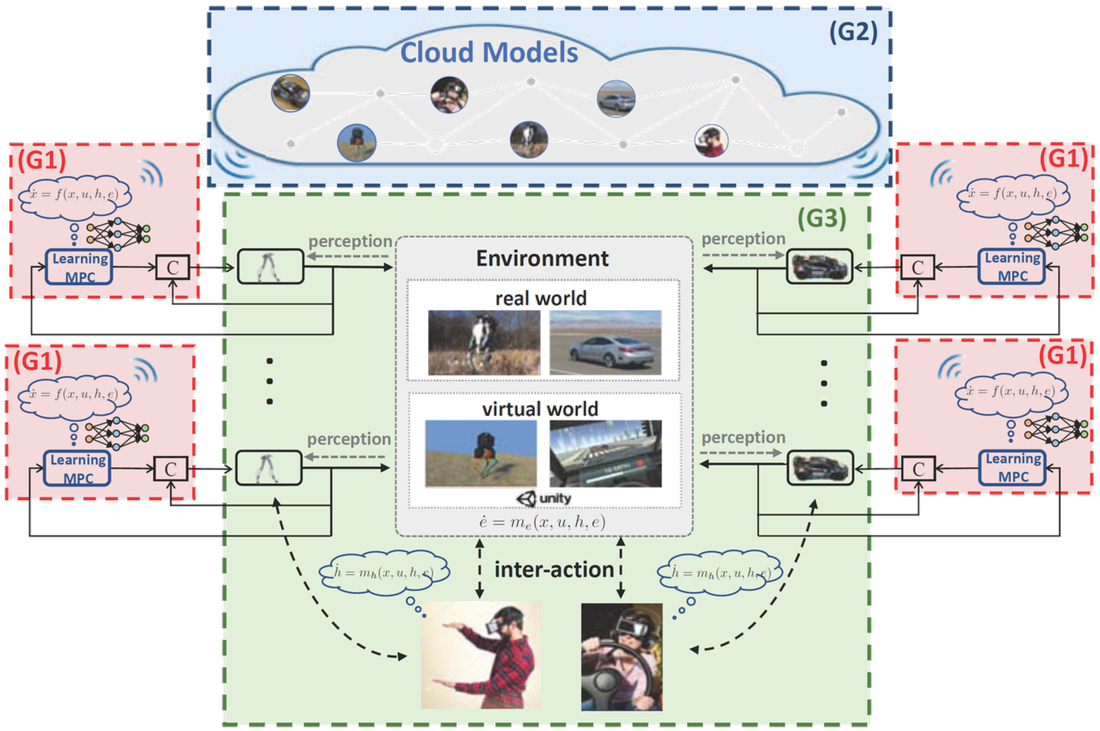
Motivation

- Need Co-Robots teams that work on dynamic tasks in complex environments.
- Current control designs for robotic systems assume (i) no human interaction with the system and (ii) precise knowledge of the environmental interaction.

Objectives

- Merge statistical learning theory with predictive control theory using a mix of physics-based and data-driven models in the learning process. Focus on guarantees of performance improvement and safety during learning.
- Sharing models between robots and humans leads to personalization. Study fundamental trade-offs between personalization and safety.
- Use Human-Hardware-in-the-loop (HHIL) platforms to speed up generation of realistic data-sets.



Safe and Performing Co-robots Learning

- Unify Physics-based and Data-driven Modeling
- Establish bounds on approximation error
- Learning-based Predictive Control

$$
\begin{aligned}
x_{t+1} &= \bar{f}(x_t, u_t, h_t, e_t, d_t) + w_t \\
d_t &= \tilde{f}(x_t, u_t, h_t, e_t)
\end{aligned}
$$

$$
\min_{\pi_{t|t}(\cdot),\ldots,\pi_{t+N-1|t}(\cdot)} \sum_{k=t}^{t+N-1} \mathbb{E}\left[\ell(x_{k|t}, u_{k|t})\right] + \mathbb{E}\left[Q(x_{t+N|t})\right]
$$

$$
\begin{aligned}
& x_{t|t} = x(t),\ e_{t|t} = e(t),\ h_{t|t} = h(t), \\
\text{Robot Model} \quad & x_{k+1|t} = \bar{f}(x_{k|t}, u_{k|t}, h_{k|t}, e_{k|t}, \tilde{f}(x_{k|t}, u_{k|t}, h_{k|t}, e_{k|t})) + w_{k|t}, \\
\text{Environment Model} \quad & e_{k+1|t} = m_e(x_{k|t}, u_{k|t}, h_{k|t}, e_{k|t}), \\
\text{Human Model} \quad & h_{k+1|t} = m_h(x_{k|t}, u_{k|t}, h_{k|t}, e_{k|t}), \\
& u_{k|t} = \pi_{k|t}(x_{k|t}, h_{k|t}, e_{k|t}), \\
& g(x_{k|t}, u_{k|t}, h_{k|t}, e_{k|t}) \leq 0
\end{aligned}
$$

for all

$$
\begin{aligned}
& \tilde{f}(\cdot) \in \mathcal{F}_{\tilde{f}} \\
& m_e(\cdot) \in \mathcal{F}_{m_e} \\
& m_h(\cdot) \in \mathcal{F}_{m_h} \\
& w_{k|t} \in \mathbb{W},
\end{aligned}
$$

Personalization and its effect on Safety

- Robots push their collected models (ego, environment and human models) and relevant data to the cloud to be shared by all robots.
- Full Personalization and Common Control Updates.

HHIL Platforms

- Dynamic Legged Robots
- Selected experiment link

Broader Impacts (Education/Outreach)

- HHIL Platform will be used to lower barriers in teaching co-robots in large classes.
- PIs will teach new course on co-robot control design and optimization with machine learning.

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