Intention-based motion adaptation using dynamical systems with human in the loop

Mahdi Khoramshahi and Aude Billard

Motivation

Physically collaborative robots

A seamless human-robot interaction requires several robotic roles:

- ☑ Passive follower
- ☑ Compliant leader
- ❑ Proactive follower

Prediction and adaptation on different levels:

☑ Force ☑ Motion ❑ Task

Approach

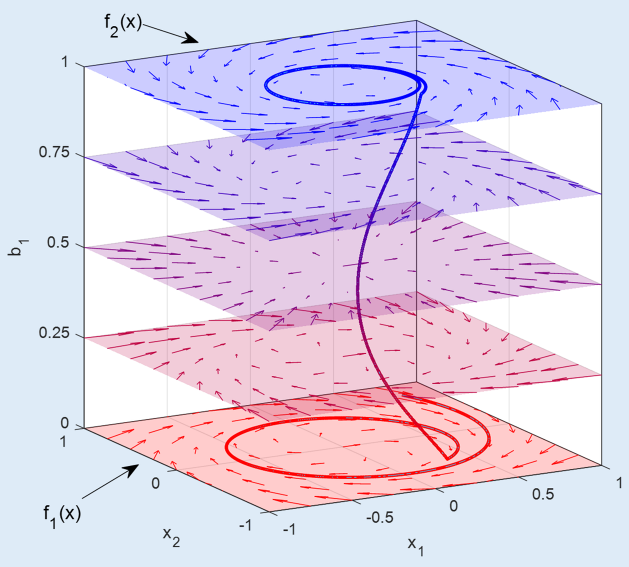
Dynamical systems for motion planning

A state-dependent dynamical system ($f: \mathbb{R}^n \to \mathbb{R}^n$) that maps the robot's position to the desirable velocity in order to execute a specific task

$$\dot{x}_d = f(x_r)$$

Such models can be learned from human demonstrations in a **stable** and **smooth** manner.

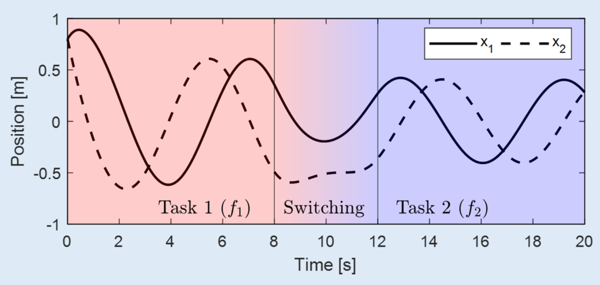
The model generalizes to the unseen contexts and provides **reactive** motion-planning.



This approach can be extended to encode for several tasks:

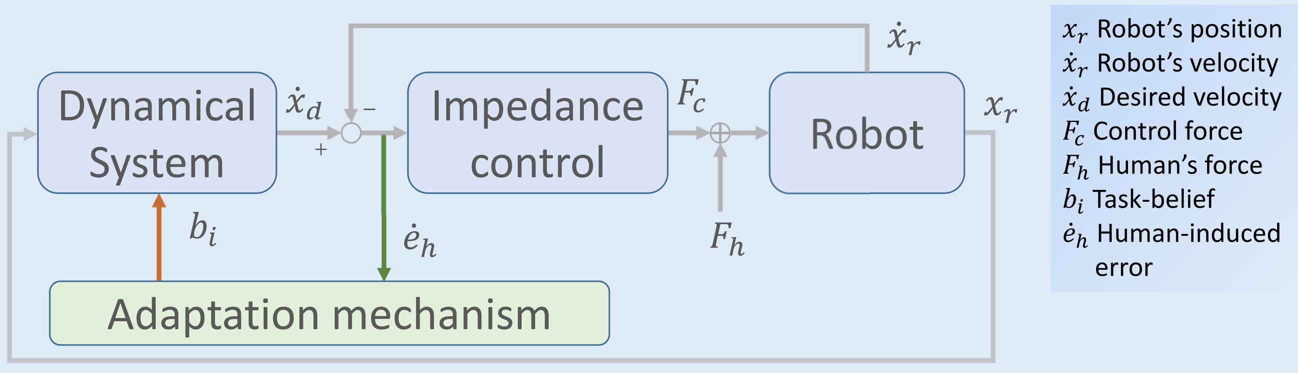
$$\dot{x}_d = \sum_{i=1}^{N} b_i\, f_i(x_r)$$

$b_i \in [0,1]$ and $\sum_i b_i = 1$



where each dynamical system is weighted with its corresponding belief. This structure allows for **smooth transitions between tasks.**

DS-based impedance control



Impedance controller: $F_c = -d(\dot{x}_r - \dot{x}_d)$

Task adaptation

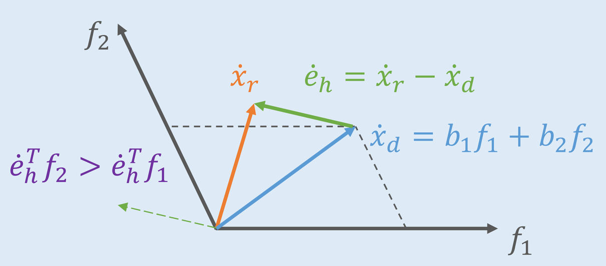
The task-beliefs are updated based on the human interaction:

$$\dot{\hat{b}}_i = \epsilon\left[\dot{e}_h^T f_i(x_r) + (b_i - 0.5)|f_i(x_r)|^2\right]$$

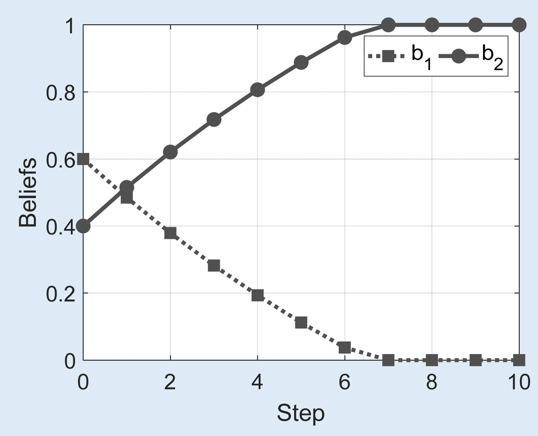
where ϵ is the adaptation rate. The computed values ($\dot{\hat{b}}_i$) are modified based on the following winner-take-all process.

Winner-take-all
$w \leftarrow \arg\max_i \dot{\hat{b}}_i$
if ($b_w = 1$) then
$\quad \dot{b}_i \leftarrow 0 \quad \forall i$
$\quad$ Return $\dot{b}_i$
else
$\quad v \leftarrow \arg\max_i \dot{\hat{b}}_i \quad \forall i \neq w$
$\quad z \leftarrow \left(\dot{\hat{b}}_w + \dot{\hat{b}}_v\right)/2$
$\quad \dot{b}_i \leftarrow \dot{\hat{b}}_i \quad \forall i$
$\quad S \leftarrow 0$
$\quad$ for i do
$\quad\quad$ if ($b_i \neq 0$ OR $\dot{b}_i$) then
$\quad\quad\quad S \leftarrow S + \dot{b}_i$
$\quad \dot{b}_w \leftarrow \dot{b}_w - S$

Interpreting the error w.r.t each task:



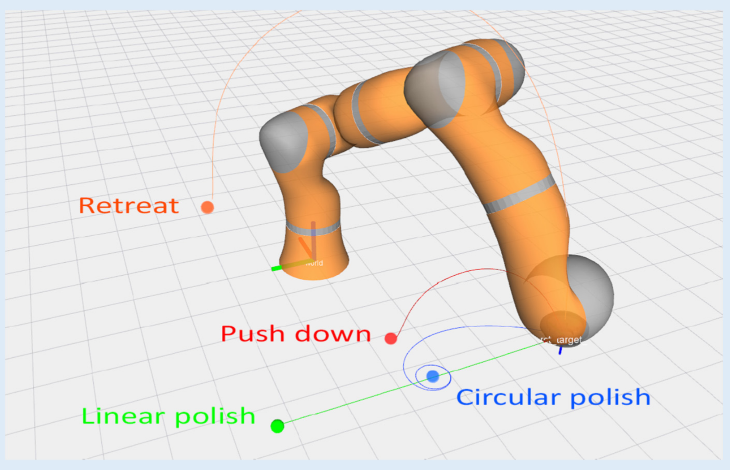
Increasing the belief of the most similar task:

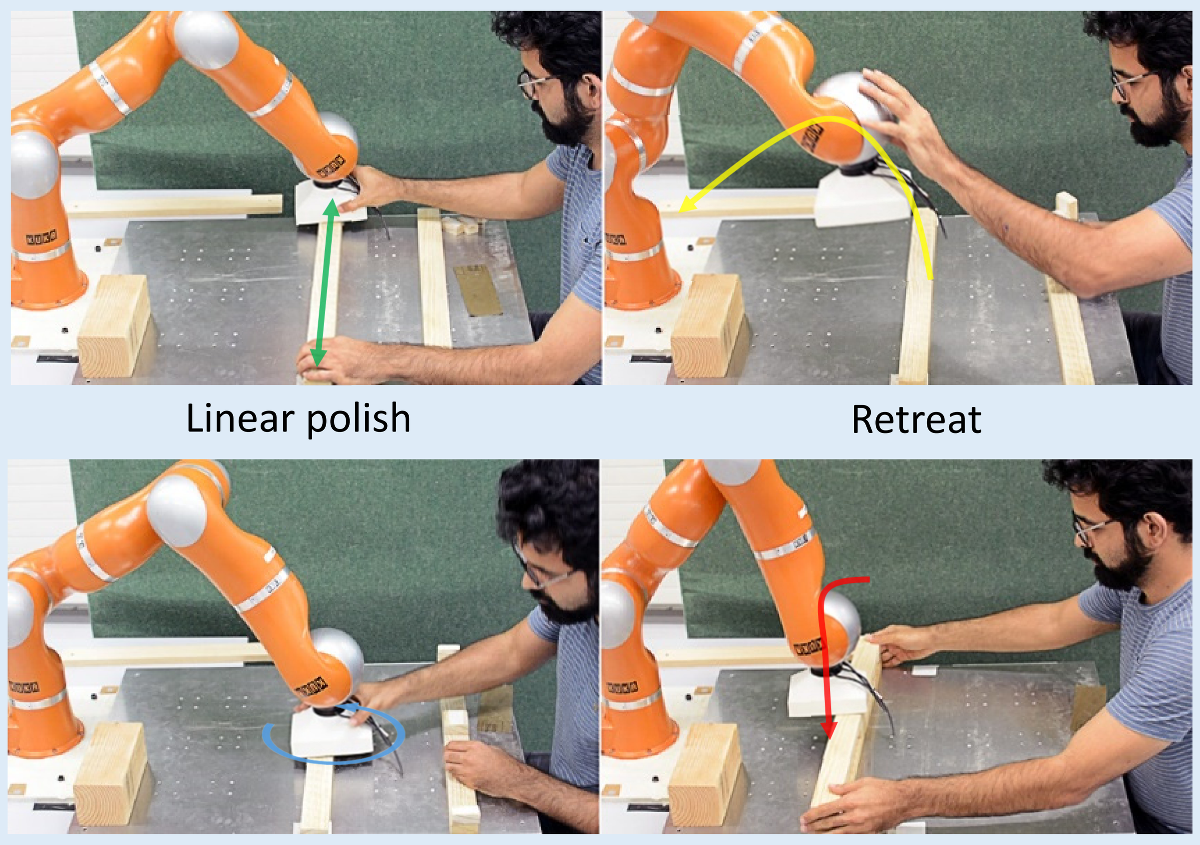


Experimental evaluation

Scenario

The robot consists of a 7-DOF KUKA LWR 4+ arm with a flat (plastic) end-effector where a sand-paper is attached.



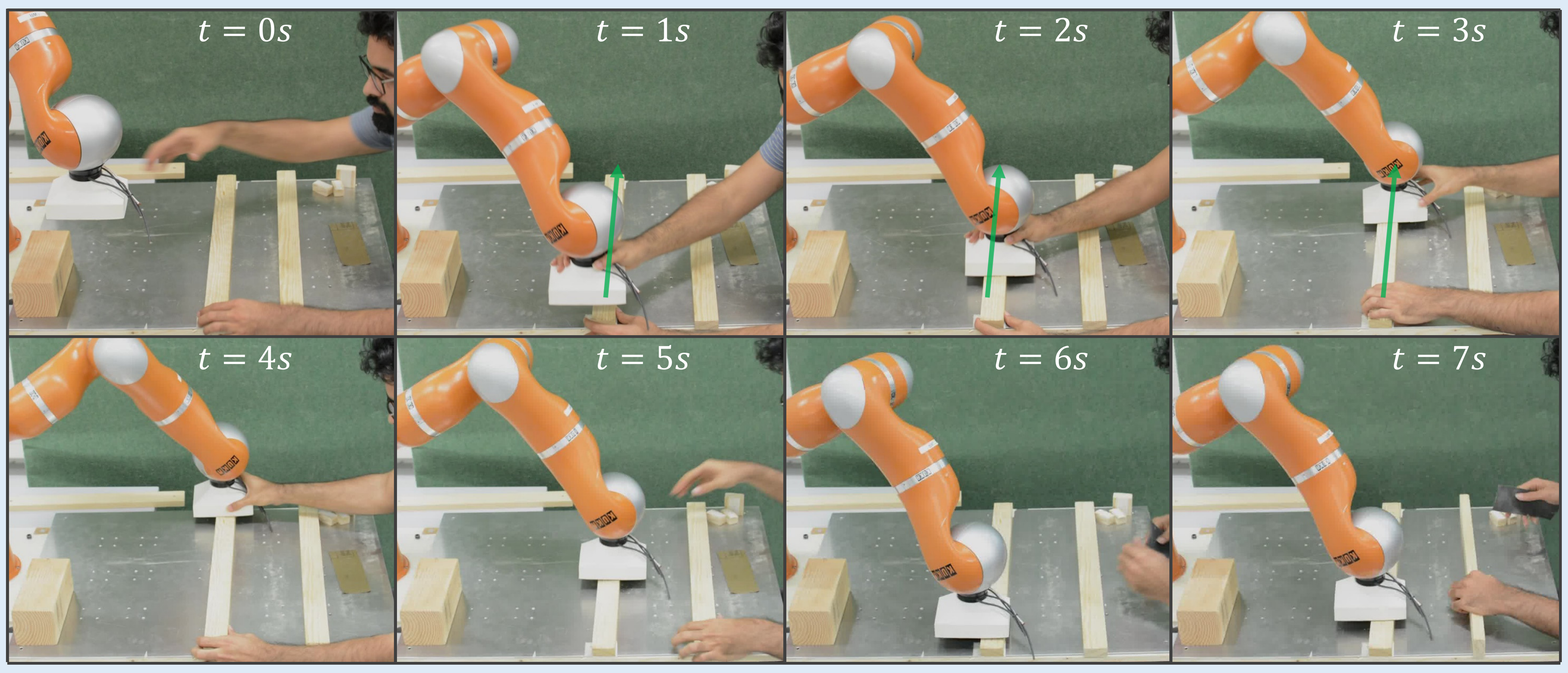


Linear polish Retreat

Circular polish Push down

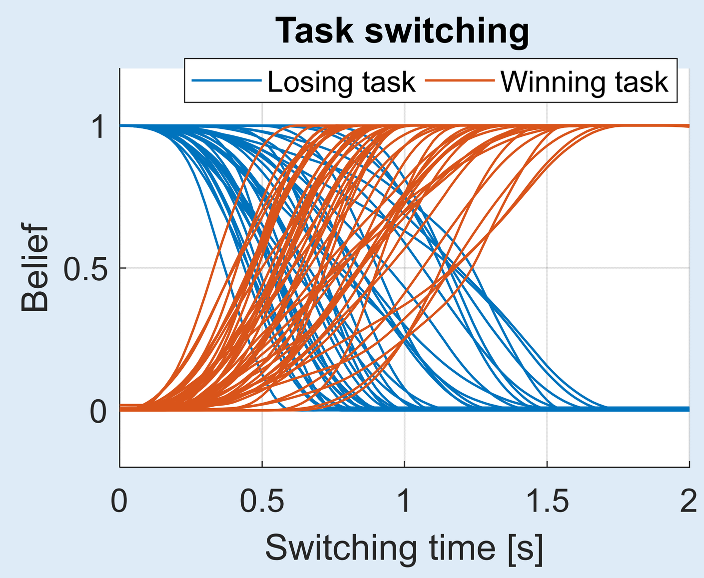
- ❑ Different robotic tasks are implemented using dynamical systems.
- ❑ In any given state, the robot is able to smoothly switch across tasks.
- ❑ DS-impedance control allows for compliant interaction with the environment while executing a task.
- ❑ The human physically interacts with the robot and demonstrates his/her intention.
- ❑ The robot recognizes the human's intention and smoothly switches to the intended task.

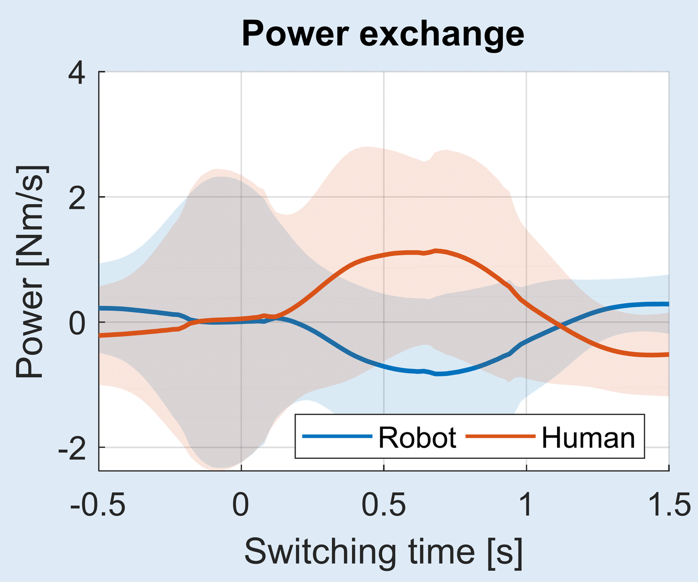
Results



- ❑ After a short demonstration (3 seconds), the robot recognizes the human intention and becomes active in the interaction.
- ❑ The required effort for task-switching is determined by the adaptation speed and the impedance gain
  - ➢ Tracking vs. compliant behavior
- ❑ The speed of convergence is affected by
  - ➢ Adaptation rate (ϵ): Fast vs. robust convergence.
  - ➢ Human demonstrations: Similarity of demonstration to the target task.
  - ➢ Distinguishability of the tasks: Dissimilarity across tasks.

The full demonstration can be viewed using this QR code.





Conclusions

Our experimental results show that the **adaptive dynamical system** approach is an effective tool in achieving proactivity in physical human-robot interaction. We proposed a formulation to **encode several robotic tasks** in the motion-planner which allows for **smooth task-transitions**. Moreover, using the proposed adaptation mechanism, the robot **recognizes the human's intention** and adapts its task accordingly. This prediction capacity at the task-level contributes to the **robot's proactivity** in its physical collaborations with the human user.

References

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[2] Kronander K, Billard A. Passive interaction control with dynamical systems. RAL 2016.
[3] Khoramshahi M, Billard A. A dynamical system approach to task-adaptation in physical human–robot interaction. AR 2018

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