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

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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

Dynamical systems for motion planning

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

$\ddot{x}_d = f(x_d)$

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 several tasks:

$\ddot{x}_d = \sum_{i} h_i f(x_d)$

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

DS-based impedance control

Task adaptation

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

$\delta_i = e \left[ \frac{1}{2} \left( f_i(x_d) + (h_i - 0.5) f_i(x_c) \right) \right]^2$

where $e$ is the adaptation rate. The computed values ($\delta_i$) are modified based on the following winner-take-all process.

Winners-take-all

1. $w = \arg \max \delta_i$
2. if ($\delta_i = 1$) then
3. $h_i = 0 \forall i \neq w$
4. Return $h_i$
5. else
6. $v = \arg \max \delta_i \forall i \neq w$
7. $z = (\delta_i + \delta_v)/2$
8. $h_i = h_v \forall i$
9. $S = 0$
10. for $i$ do
11. if ($h_i \neq 0 \text{ OR } \delta_i \neq 1$) then
12. $s = S + S + h_i$
13. $h_i = h_v - s$

Increasing the belief of the most similar task:

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


Scenario

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

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

Conclusions

The full demonstration can be viewed using this QR code.

The speed of convergence is affected by
- Adaptation rate ($c$): Fast vs. robust convergence.
- Human demonstrations: Similarity of demonstration to the target task.
- Distinguishability of the tasks: Dissimilarity across tasks.

Tracking vs. compliant behavior