Acting on Push Affordances: Adapting Dynamic Movement Primitives Based on Object Behaviour

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Abstract

***Nonprehensile* manipulation such as pushing can play a significant role in complex scenarios. Objects may have diverse, even anisotropic properties under pushing in different environments. This increases the complexity of the pushing problem. We propose an approach to adapting dynamic movement primitives (DMPs) based on the observed object-motion behaviour and experienced forces. We also investigate alternative techniques that enable dexterous and adaptive manipulation using pushability and manipulability of objects: optimal control and reactive control.**

Motivation

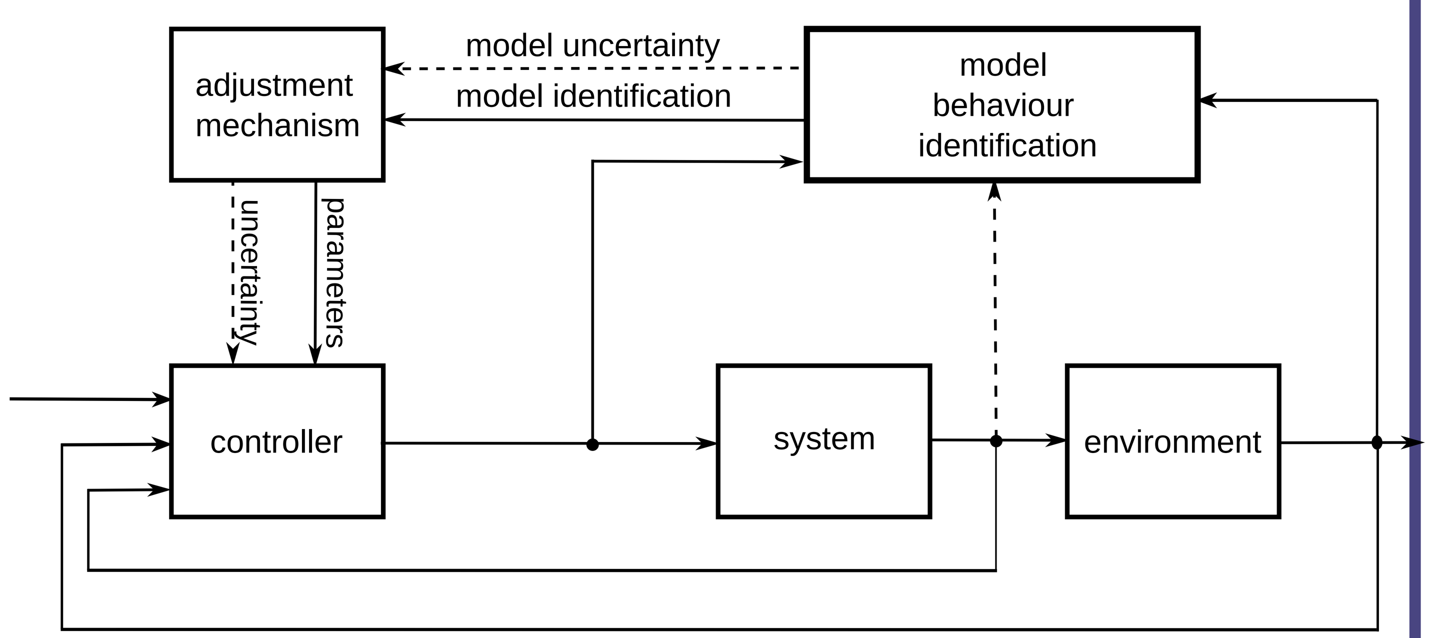
Humans and animals often use pushing as part of manipulative skills. Enabling similar pushing skills for robots can serve multiple purposes:

- correcting the placement of an object,
- clearing paths and shoving objects into free space,
- manoeuvring large objects and objects hard to grasp,
- enhancing pick-and-place operations.

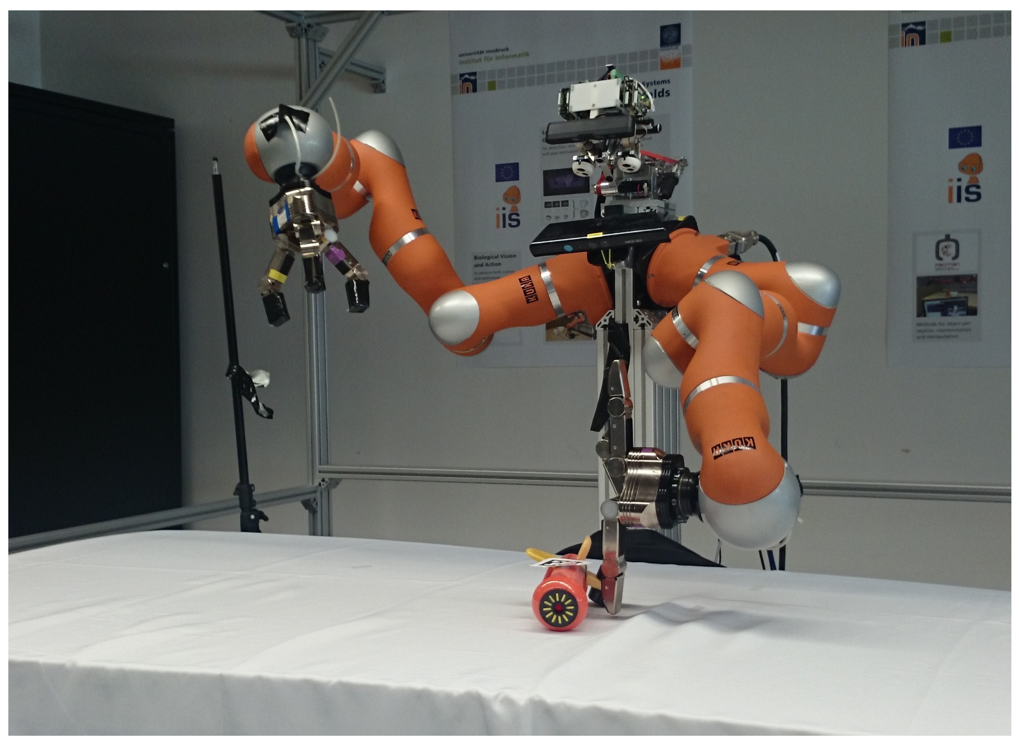
In our preliminary experiments, we observed that single-contact pushing of objects even in a straight line is not trivial due to differing properties of objects.

Adaptive Control Approach

In a pushing task, the robot is assumed to have no previous knowledge of the object. By pushing the object, it is possible to build an object behaviour model *on the fly* based on observations of object-environment dynamics. This model is then used to adjust the **robot motion controller**. At the onset of a manipulation, the object is assumed to have ideal properties for pushing, moving only together with the robot.



Adjusting DMPs



Introducing corrective actions in a pushing task is possible by sensing. Control parameters are adapted based on the pushing experience to provide desired object movements. Online modulation of dynamic movement primitives is done by adding coupling terms. These terms alter a primitive based on intermediate success of object behavior and experienced forces.

$$
\begin{aligned}
\tau\dot{z} &= \alpha_z(\beta_z(g-y)-z)+f(x)+I_O\\
\tau\dot{y} &= z\\
\tau\dot{x} &= \frac{-\alpha_x}{1+\alpha_e J_e}\\
I_O &= K_{tp}p(E\left[x_O\right]-x_O)+\\
& K_{tF}f(E\left[F|e_{\min}\right]-F)\\
J_e &= \int_{t_0}^{t_c} d\left(p_d\left(\gamma\right),x_O\right)\mathrm{d}t
\end{aligned}
$$

$K_{tp} = f(\mathrm{var}(x_O),E(x_O))$ and $K_{tF} = f(\nabla F,F)$ are time-varying task sensitivities with respect to object pose and force.

Optimal Control

We propose an *optimal control* strategy with respect to the pushing objectives. These objectives define the cost function:

- The object should be delivered to the target pose fast as possible within given tracking-accuracy constraints.
- Non-smooth and jerky movements of the robot should be minimized.

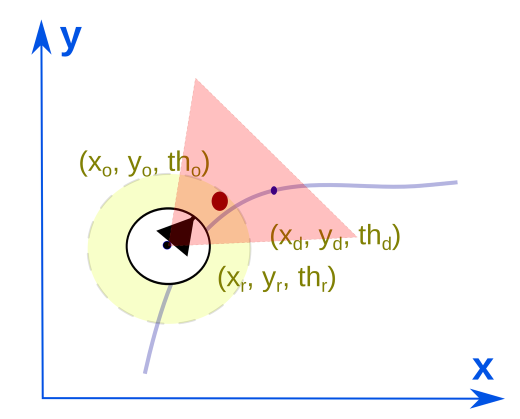
$$J = c_t\int_{t_0}^{t_f} t\,\mathrm{d}t + c_j\int_{t_0}^{t_f}\sum_{i=1}^{N}\left(\frac{\mathrm{d}^3 x_i}{\mathrm{d}t^3}\right)^2\mathrm{d}t$$

The constraints for pushing are

- first-order robot and object-environment dynamic constraints and initial conditions,
- the desired path $p_d(\gamma)$ parametrized by $\gamma \in R$ with given tolerance ρ.

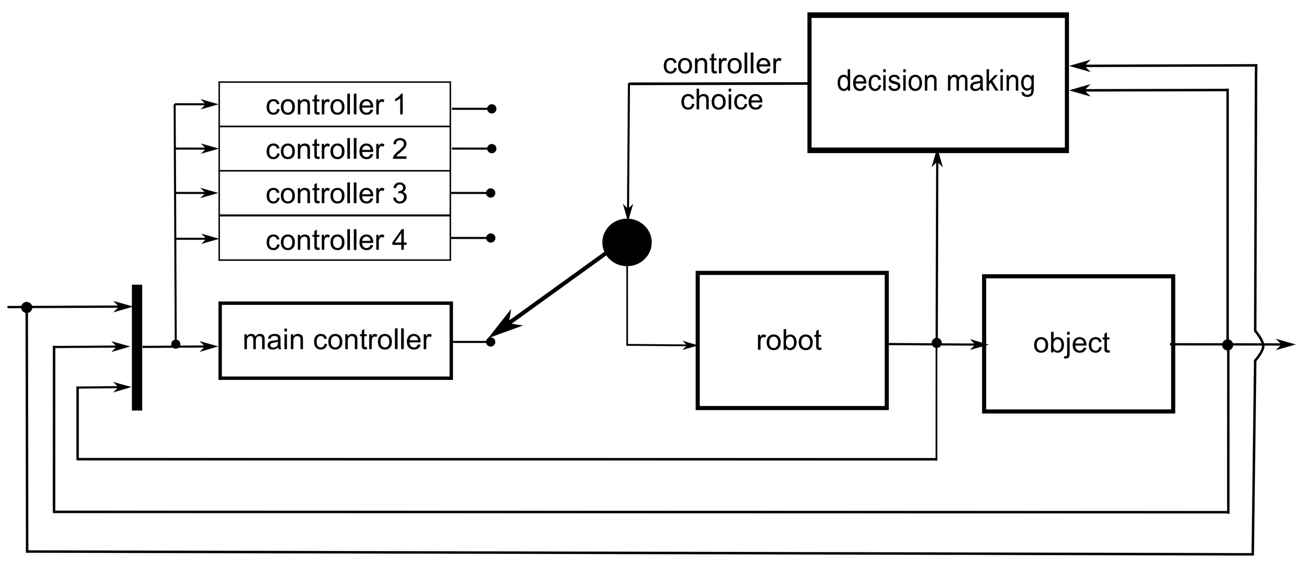
$$
\begin{aligned}
\text{s.t.}\ \ \dot{\mathbf{q}}_R(t) &= f_R\left(\mathbf{q}_R(t),\mathbf{u}_R(t)\right),\\
\dot{\mathbf{q}}_O(t) &= f_O\left(\mathbf{q}_O(t),\mathbf{q}_R(t)\right),\\
\mathbf{q}_R(0) &= \mathbf{q}_{R0}, \mathbf{q}_O(0) = \mathbf{q}_{O0},\\
\min_{\gamma} d\left(E\left[\mathbf{P}_O(t+\delta t)\right],p_d(\gamma)\right) &< \rho
\end{aligned}
$$

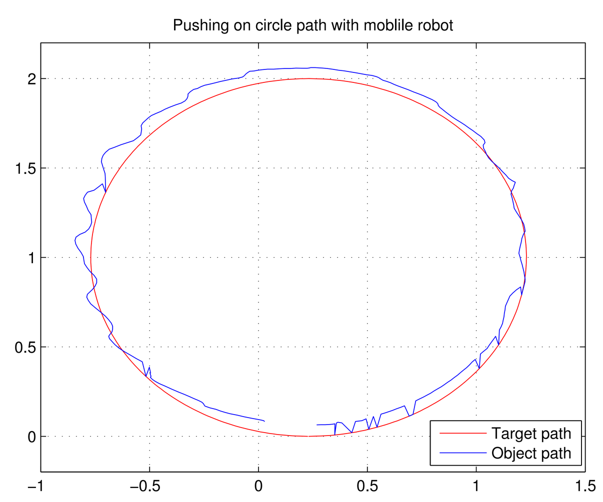
Reactive Control



We propose a *reactive control* strategy based on distinct object behaviours. A robot can detect these behaviours and react correspondingly by switching between different actions:

- Main pushing control
- Controllers reacting on changes in path curvature
- Controllers for object seeking and following





References

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(2) F. Ruiz-Ugalde, G. Cheng, and M. Beetz. Fast adaptation for effectaware pushing. Humanoids 2011, pp. 614–621.

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