Dynamic Movement Primitives–A Framework for Motor Control in Humans and Humanoid Robotics

Stefan Schaal

Computer Science and Neuroscience, University of Southern California, Los Angeles, CA 90089-2520, USA
ATR Human Information Science Laboratory, 2-2 Hikaridai, Seika-cho, Soraku-gun, 619-02 Kyoto, Japan

1 Introduction

Given the continuous stream of movements that biological systems exhibit in their daily activities, an account for such versatility and creativity has to assume that movement sequences consist of segments, executed either in sequence or with partial or complete overlap. Therefore, a fundamental question that has pervaded research in motor control both in artificial and biological systems revolves around identifying movement primitives (a.k.a. units of actions, basis behaviors, motor schemas, etc.). This paper summarizes results that led to the hypothesis of Dynamic Movement Primitives (DMP). DMPs are units of action that are formalized as stable nonlinear attractor systems. They are useful for autonomous robotics as they are highly flexible in creating complex rhythmic (e.g., locomotion) and discrete (e.g., a tennis swing) behaviors that can quickly be adapted to the inevitable perturbations of a dynamically changing, stochastic environment. Moreover, DMPs provide a formal framework that also lends itself to investigations in computational neuroscience. A recent finding that allows creating DMPs with the help of well-understood statistical learning methods has elevated DMPs from a more heuristic to a principled modeling approach.

2 Dynamic Movement Primitives

Using nonlinear dynamic systems as policy primitives is the most closely related to the original idea of motor pattern generators (MPG) in neurobiology. We assume that the attractor landscape of a DMP represents the desired kinematic state of a limb, e.g., positions, velocities, and accelerations. As shown in Figure 1, kinematic variables are converted to motor commands through an inverse dynamics model and stabilized by low gain feedback control. The motivation for this approach is largely inspired by data from neurobiology that demonstrated strong evidence for the representation of kinematic trajectory plans in parietal cortex [1] and inverse dynamics models in the cerebellum [2, 3]. However, it should be noted that a kinematic representation of movement primitives is not necessarily independent of dynamic properties of the limb. Proprioceptive feedback can be used to modify the attractor landscape of a DMP in the same way as perceptual information [4-6].

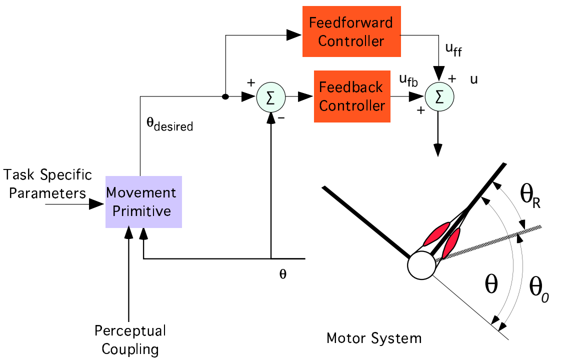

Figure 1: Sketch of control diagram with dynamic movement primitives. Each degree-of-freedom of a limb has a rest state θ_o and an oscillatory state θ_r .

3 Summary of Results

Theoretical insights, evaluations on a humanoid robot, behavioral data from experiments with human subjects, and brain imaging data support the framework of DMPs as a general approach to motor control in robotics and biology. We believe that the combination of robotic, theoretical, and biological work that we pursued for the presented studies exemplifies a new path towards research in biomimetic robotics and computational neuroscience. Both disciplines can offer new ideas and techniques that will ultimately lead to reciprocal benefits in both disciplines.

References

[1] J. F. Kalaska, "What parameters of reaching are encoded by discharges of cortical cells?," in *Motor Control: Concepts and Issues*, D. R. Humphrey and H. J. Freund, Eds.: John Wiley & sons, 1991, pp. 307-330.

[2] N. Schweighofer, M. A. Arbib, and M. Kawato, "Role of the cerebellum in reaching movements in humans. I. Distributed inverse dynamics control," *Eur J Neurosci*, vol. 10, pp. 86-94, 1998.

[3] N. Schweighofer, J. Spoelstra, M. A. Arbib, and M. Kawato, "Role of the cerebellum in reaching movements in humans. II. A neural model of the intermediate cerebellum," *Eur J Neurosci*, vol. 10, pp. 95-105, 1998.

[4] A. A. Rizzi and D. E. Koditschek, "Further progress in robot juggling: Solvable mirror laws," presented at IEEE International Conference on Robotics and Automation, San Diego, CA, 1994.

[5] S. Schaal and D. Sternad, "Programmable pattern generators," presented at 3rd International Conference on Computational Intelligence in Neuroscience, Research Triangle Park, NC, 1998.

[6] M. Williamson, "Neural control of rhythmic arm movements," *Neural Networks*, vol. 11, pp. 1379-1394, 1998.