Guiding self-organization applied to an anthropomorphic tendon driven arm.

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Controlling robotic systems is a challenging task. For rigid body systems good analytical models are available which allow for an efficient and stable control for a given target trajectory. If the hardware is soft or is driven by tendons the situation is different. Recently, more and more soft systems are build because they are safer to interact with and thus favorable for service robots in human environments. Unfortunately, analytical models are not available for this case and classical control cannot be applied as is. Apart from that finding a suitable trajectory for a particular task is also an extremely hard task, typically approached with reinforcement learning and optimization. However, without a compact parametrization learning a new behavior with these techniques takes a very long time in high-dimensional systems. We show that self-organized behavior can solve parts of both problems at the same time. By considering the sensorimotor loop as a dynamical system and adapting the parameters online based on a simple function of the behavior in the recent past, we build a system that has a set of interesting features: (i) it creates spontaneous behaviors due to self-amplification that fit to the controlled system, (ii) it excites latent modes of the combined system of body and environment, and (iii) it is fully deterministic. The controller can be implemented by a neural network with a novel synaptic plasticity rule (Der and Martius, 2015, 2016), as shown in Fig. 1. In comparison to other synaptic rules, responses of the world to actions directly enters the update equation which makes the system strongly dependent on the particular embodiment and also allows for manual interaction with the robot.

We report on experiments with a real tendon driven arm with a ball and socket shoulder joint and 9 muscles in total. The system has some peculiarities, e. g. the muscles are elastic, such that there are infinitely many combinations of motor positions for a single arm pose. Apart from that the shoulder joint dislocates as soon as the tendons become slack. Astonishingly, although structurally extremely simple, the new control paradigm does not have problems with these particularities. For instance the tendons are kept tight automatically, such that no dislocation appears. The new dynamical system of arm and controller displays a rich behavioral spectrum like limit cycle attractors (i. e. the arm starts to shaking a bottle with water), long lived transients (i. e. behaviors are slowly changing), and fixed point flows generating pseudo-random sequences of poses. The concrete behavior is not given explicitly, but specific behaviors develop by themselves in a self-organized way from the dynamical interplay between controller dynamics and world dynamics.

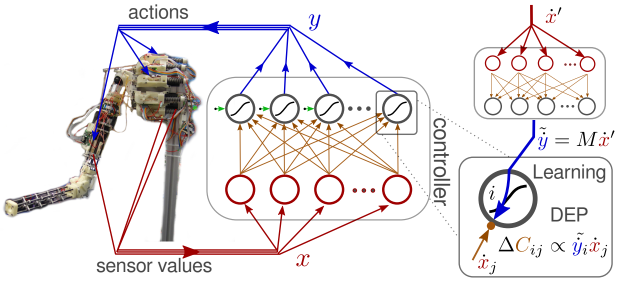

Figure 1: **Neural controller network connected to the Myo-robotic arm.** The inset on the right illustrates the synaptic plasticity, called differential extrinsic plasticity, which is driven by a modified differential Hebbian law, multiplying the time derivatives of the incoming sensor values $\dot{x}$ with the virtual motor values $\tilde{y}$, which are generated by the inverse model (M, one-to-one mapping in the case of the arm) from next input's derivative $\dot{x}'$.

An interesting property of the control approach is that it can be guided by manual interaction. The user can always grab the arm and it will almost instantaneously stop to move. When the user moves it in a desired way the resulting behavior may either just follow the demonstration or a new "negotiated" behavior emerges, which is due to the integration of the user into the sensorimotor loop. The controller changes quickly, but for any exhibited behavior it can be simply stored and restored later. Interestingly, these controller have a large basins of attraction, such that switching between different behaviors can be achieved by simply switching the controllers. We demonstrate this in a set of experiments, among others where the arm was guided to wipe a table or to turn a wheel in different ways. Latest results also demonstrate the automatic integration of vision sensors such that a visuo-manual coordination emerges. This can be used to recall a behavior from a visual percept and to create a restricted object following behavior. Some videos can be found at `playfulmachines.com/MyoArm-2`).

References

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