CPG-Like Motor Control Model for Periodic Arm Motion

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Despite the extensive redundancy in human anatomy, the central nervous system (CNS) manages to control every task efficiently and accurately. There are various pieces of evidence showing that rhythmic limb motion is primarily controlled by the neural circuits within the spinal cord called central pattern generators (CPGs). CPG models are particularly interesting as they can efficiently address the redundancy in human anatomy by locally translating low dimensional central commands (e.g. speed of walking) to the high-dimensional actuator space.

We have developed a CPG-like motor control model which can drive a musculoskeletal forearm model with a periodic motion, by just a one-dimensional command specifying the desired motion frequency. The model provides a framework to examine the possible ways the CNS controls body motion. The arm model is a one degree of freedom system, actuated by four muscle groups: biceps and triceps brachii, brachioradialis, and brachialis.

Complicated excitation patterns cannot be achieved with the current half-centre-based CPG models. Our motor control model has a layered structure. The first layer, the pacemaker, determines the speed of the motion (tempo), whereas the second layer, the pattern generator, builds the appropriate muscle excitation pattern (melody). The periodic excitation patterns are built upon the output of the pacemaker; however, since the dynamics of the arm and muscles is nonlinear, the muscle excitation patterns generated by the pattern generator have to be modified for different desired frequencies of motion.

The Fourier series is an excellent candidate for building the muscle excitation patterns. First, the patterns can be based upon the harmonics, generated by the pacemaker; second, arbitrary patterns can easily be approximated by modifying Fourier series coefficients at each desired frequency.

Sets of optimal Fourier coefficients for a number of desired frequencies are calculated so that the arm follows the desired motion, and the muscle activations are minimized. These optimal Fourier coefficients are stacked in a look-up table. Then for an arbitrary desired frequency, the data in the look-up table is interpolated to find the corresponding coefficients. They are used in the Fourier series to build the (optimal) muscle excitations with little computational time.

Finally, the motor control model is implemented with ensembles of spiking neurons. The implementation is based on the Neural Engineering Framework [1]. The stochastic behavior of the neurons results in indeterministic arm motions; however, the motor control model manages to follow the desired frequency, and the average motion matches the desired motion.

Reference

[1] Eliasmith, C., Stewart, T. C., Choo, X., Bekolay, T., DeWolf, T., Tang, Y., … Rasmussen, D. (2012). A large-scale model of the functioning brain. Science (New York, N.Y.), 338(6111), 1202–5. doi:10.1126/science.1225266