Evaluating Morphological Computation in Muscle and DC-motor Driven Models of Human Hopping

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Morphological computation (MC) is relevant in the study of biological and robotic systems. In robotics, a quantification of MC can be used e.g. as part of a reward function in a reinforcement learning setting to encourage the outsourcing of computation to the morphology, thereby enabling complex behaviors that result from comparably simple controllers. The relationship of embodiment and controller complexity has been recently studied in (Montúfar et al., 2015). MC measures can also be used to evaluate the robot's morphology during the design process. For biological systems, energy efficiency is important and an evolutionary advantage. Exploiting the embodiment can lead to more energy efficient behaviors, and hence, MC may be a driving force in evolution.

In biological systems, movements are typically generated by muscles. Several simulation studies have shown that the muscles' typical non-linear contraction dynamics can be exploited in movement generation with very simple control strategies (Schmitt and Haeufle, 2015). Muscles improve movement stability in comparison to torque driven models (van Soest and Bobbert, 1993) or simplified linearized muscle models (for an overview see Haeufle et al., 2012). Muscles also reduce the influence of the controller on the actual kinematics (they can act as a low-pass filter). This means that the hopping kinematics of the system is more pre-determined with non-linear muscle characteristics than with simplified linear muscle characteristics (Haeufle et al., 2012). And finally, in hopping movements, muscles reduce the control effort (amount of information required to control the movement) by a factor of approximately 20 in comparison to a DC-motor driven movement (Haeufle et al., 2014).

In view of these results we expect that MC plays an important role in the control of muscle driven movement. To study this quantitatively, a suitable measure for MC is required. There are several approaches to formalize MC (Hauser et al., 2011; Polani, 2011; Rückert and Neumann, 2013). In our previous work we have focused on an agent-centric perspective of measuring MC (Zahedi and Ay, 2013) and we have applied an information decomposition of the sensorimotor loop to measure and better understand MC (Ghazi-Zahedi and Rauh, 2015). Both publications used a binary toy world model to evaluate the measures.

In this publication, we evaluate two information-theoretic measures of MC on biologically realistic hopping models. With this, we demonstrate their applicability in non-trivial, realistic scenarios. In accordance with our previous findings (see above), we show that MC is higher in hopping movements driven by a non-linear muscle compared to those driven by a simplified linear muscle or a DC-motor. Furthermore, our experiments show that a state-dependent analysis of MC for the different models leads to insights, which cannot be gained from the averaged measures alone.

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