DOI: http://dx.doi.org/10.7551/978-0-262-33027-5-ch015

Musculo-Skeletal Models as Tools to Quantify Embodiment

Daniel F. B. Haeufle[1], Michael Günther[1], and Syn Schmitt[1]

[1]University of Stuttgart, 70569 Stuttgart, Germany
daniel.haeufle@inspo.uni-stuttgart.de

Musculo-skeletal models

Human and animal movement is absolutely fascinating and can hardly be mimicked by technical devices, so far. It has been proposed that part of the movement generation and control can be associated to the non-linear characteristics of the bio-mechanical structures and morphology. Terms like *morphological computation* (Paul, 2006) and *intelligence by mechanics* (Blickhan et al., 2007) capture this idea.

Musculo-skeletal models allow to synthesize biological movements based on models representing the non-linear characteristics of muscles, tendons, ligaments, and other bio-mechanical structures. This approach allows for studying the contribution of these structures and, thus, their role in the control of human and animal movements.

Quantifying control effort with information entropy

In a recent study (Haeufle et al., 2014), we showed that the control effort of periodic hopping is reduced by the muscle contraction dynamics (32 Bits) as compared to DC-motor characteristics (660 Bits). To quantify control effort we proposed to measure the minimal information $I_{\min}$ required to control hopping. The information transmitted from a digital sensor to an actuator (muscle, DC-motor) can be quantified based on Shannon's information entropy. In a typical technical implementation, the controller assumes equal probability $p_i = 1/n$ of each of the n possible sensor values when digitizing a physical signal u. With this assumption, the total information transmitted with a signal is $I = \frac{T}{\Delta t} \log_2 \left(1 + \frac{u_{\max} - u_{\min}}{\Delta u}\right)$, where $u_{\min} \leq u \leq u_{\max}$ is the range of the sensor, Δu its amplitude resolution, Δt the temporal resolution, and T the total duration of the movement. The minimally required information $I_{\min}$ for a given actuator and controller was found by varying the parameters Δu and Δt under the constraint that hopping height and frequency were still in a biologically realistic range.

Similar to the quantification of *relevant information* introduced by Polani et al. (2006), we also limit the information transmitted to the actuator to identify the minimal information required for a given task. However, we focus on modifying the internal dynamics of the agent (muscle vs. DC-motor) and study the effect on $I_{\min}$ to ultimately study biological design, and, thus, embodiment. For a system generating hopping with coarse signal resolution and therefore little processed information, the control effort is low and the control is simple.

New perspective

The musculo-skeletal models developed in our group represent the physiological and morphological structure of biological agents in a level of detail which is adequate for studying typical movements. It is possible to vary the physiological and morphological structures and properties and, hence, to study their role in movement control. We think that this approach opens up unique possibilities to quantify embodiment and even compare it to technical systems.

Our approach to control effort quantifies the minimal information $I_{\min}$, which has to be processed to generate a specific movement with a specific controller. We hypothesize, that the differences in $I_{\min}$ found by varying and exchanging structures, e.g., actuators, give insights into the amount of embodiment. To further evaluate this idea, we would like to discuss our work in the context of other recently published approaches for the quantification of embodiment and morphological computation.

References

Blickhan, R., Seyfarth, A., Geyer, H., Grimmer, S., Wagner, H., and Günther, M. (2007). Intelligence by mechanics. *Philosophical Transactions of the Royal Society of London, Series A*, 365(1850):199–220.

Haeufle, D. F. B., Günther, M., Wunner, G., and Schmitt, S. (2014). Quantifying control effort of biological and technical movements: An information-entropy-based approach. *Physical Review E*, 89(1):012716.

Paul, C. (2006). Morphological computation: A basis for the analysis of morphology and control requirements. *Robotics and Autonomous Systems*, 54(8):619–630.

Polani, D., Nehaniv, C., Martinetz, T., and Kim, J. (2006). Relevant information in optimized persistence vs. progeny strategies. In *Artificial Life X*, pages 337–343. MIT Press.

Daniel F. B. Haeufle, Michael Günther, Syn Schmitt (2015) Musculo-Skeletal Models as Tools to Quantify Embodiment.
Proceedings of the European Conference on Artificial Life 2015, p. 68