BP 37: Modelling of non-linear dynamics in biological movement (focus session)

Time: Wednesday 15:00–16:30 Location: EW 202

Invited Talk BP 37.1 Wed 15:00 EW 202

The cost of moving optimally — •Dinant Kistemaker — VU, Amsterdam, The Netherlands — UWO, London, Canada.

The field of Human Motor Control is concerned with how the brain deals with the very many kinematic and mechanical degrees of freedom (DoF) to control posture and movement. In this field, mathematical models of the musculoskeletal system are indispensable as they provide answers to questions that are inaccessible by experimental studies alone. In a recent set of studies, predictions using a detailed model of the arm together with behavioural data were used to investigate if the DoF are exploited by the brain to minimize costs at three distinct levels: the motor system's input (e.g. control effort), the motor system's mechanical output (e.g. energy) and kinematics (e.g. jerk). Subjects performed goal-directed arm movements while holding on to a robotic manipulandum in combination with visual perturbations of seen hand position. The force fields created by the robot and visual perturbations were specially designed to be able to independently change the costs at the three levels. Direct Collocation was used to translate the ODE's of the model into nonlinear constraints and were solved together with task and boundary constraints using SNOPT, while minimizing several costs at the three levels. It was found that the behavioural data was inconsistent with the notion that the brain minimizes energy expenditure. Furthermore, it was found that in selecting a kinematic path, the brain does not take into account costs that relate to the input level or the dynamic level. Movement patterns observed experimentally were only consistent with a cost function based solely on kinematic costs.

BP 37.2 Wed 15:30 EW 202

Quantifying control effort with information entropy: a new method applied to complex biological movement — •Daniel Häufle[1], Michael Günther[1], Günter Wunner[2], and Syn Schmitt[1,3] — [1]Human Movement Simulation Lab, Universität Stuttgart — [2]Institut für Theoretische Physik 1, Universität Stuttgart — [3]Stuttgart Research Centre for Simulation Technology, Universität Stuttgart

Recently, a new measure has been proposed to quantify control effort of biological and technical movement. This measure was developed to enable a quantitative evaluation of a long standing hypothesis stating that the physical structure of humans and animals allow movement generation with less control effort. In particular, it has been hypothesized that muscles with their nonlinear contraction properties reduce control effort. This new measure is based on Information Entropy and reveals that the control effort for the simple movement task of periodic hopping is only I=32bit when generated with a muscle vs. I=660bit with a DC-motor. To further investigate this hypothesis, this approach has now been applied to human walking in comparison to robotic walking. Additionally, we will show that this measure can also be applied to microscopic active brownian motion swimmers of different shape to emphasize the wide application of our approach.

BP 37.3 Wed 15:45 EW 202

Predicted stop positions used to push pointing movements into the goal — •Karl Kalveram — Tu Darmstadt and Uni Duesseldorf

Recently we performed experiments with human forearm-movements used in pointing to a remote goal. The movements were perturbed by artificial changes of the geometry of the arm-pointer arrangement. Under discontinuous visual feedback (the pointer's location being visible only at beginning and ending of the movement), the error (difference between the goal and the pointer's location at movement end) was relatively high and varied with the perturbations. Under continuous visual feedback of the pointer's momentary location, however, the error remained low and was un-correlated with the perturbations. Inspection of the kinematics revealed that ordinary negative feedback control could not explain this effect.

The paper outlines an alternative and highly non-linear mechanism capable of physically pushing the pointer's location reliably into the goal position using also the pointer's velocity, which has, too, been available in continuous visual feedback. It is the phase relationship between velocity and position, both emitted by a pattern generator, which principally enables predicting the stop position from any interim state of the movement. This provides a prediction of the error, based on which one or several scaled force impulses can be released annihilating the error at movement end.

BP 37.4 Wed 16:00 EW 202

Reafference Principle 2.0 — •Kim Joris Boström and Heiko Wagner — Motion Science, University of Münster, Germany

The reafference principle was introduced 1950 by Holst and Mittelstaedt, and its basic features have been confirmed by many experiments. It holds that the neural systems makes an efference copy that is compared with the reafference, i.e. the afferent signal resulting from movement caused by the efference, and the difference is passed to higher centers. However, efferent and afferent signals encode very different kinds of information, between which there need not exist a linear relationship. To address this problem it has been suggested that the brain involves a forward simulator to calculate the expected reafference from the efferent signal. Such mechanism, however, would require a considerable amount of neural resources and would introduce unavoidable latencies. We propose a more efficient and latency-free mechanism that does not require an efference copy but generates the movement directly together with the corresponding expected reafference. The mechanism involves a recurrent neural network that learns to generate movements from abstract movement commands, and at the same time it learns the resulting reafference from the sensory system. Afterwards, the network is able to generate both the movements together with the corresponding reafferences, and due to its intrinsic morphing capability, the network is able to flexibly interpolate and extrapolate the learned movements in synchrony with the expected reafferences. We demonstrate the modified reafference principle by computer simulations.

BP 37.5 Wed 16:15 EW 202

Wobbling masses: definite costs and potential benefits — •Michael Günther[1,3] and Syn Schmitt[1,2] — [1]Universität Stuttgart, Human Movement Simulation Lab — [2]Stuttgart Research Centre for Simulation Technology — [3]Friedrich-Schiller-Universität Jena, Lehrstuhl für Bewegungswissenschaft

Humans seem biomechanically unique in the animal kingdom. It is, though, certainly neither bipedalism nor the strung-out leg that constitutes human's uniqueness. Some birds can even sleep on just one extended leg. Rather, it is the amount of muscle mass in the legs that makes humans unique animals. Muscle masses are soft tissue attached to the skeleton. They "wobble" when the bones are mechanically excited by impacts. Macroscopic units of soft tissue can be modelled as rigid bodies ("wobbling masses") interacting visco-elastically with the skeleton. As the corresponding energy dissipation is expected to roughly scale with wobbling mass volume, we examined how much energy is actually dissipated by human wobbling masses after a leg impact. We calculated numbers from wobbling mass kinematics of the stance leg, estimated on the basis of high-speed camera sequences of human running. Comparing dissipated energy to axial leg work and joint energy balances during ground contact provides a measure of relevance for the irreversible energy loss by leg wobbling masses. We discuss functional explanations for such a unique amount of wobbling masses in human legs. We also try and explain how they yet pay off although any significant amount of irreversible energy loss would seem inefficient and thus expectably avoided by nature as good as possible.