BP 27: Modelling of non-linear dynamics in biological movement (focus session, joint BP/DY)

Time: Wednesday 14:00–16:30 Location: ZEU 250

Topical Talk BP 27.1 Wed 14:00 ZEU 250

Legged locomotion. - From biology to mechanics and return.

— •Reinhard Blickhan — Science of Motion, Jena, Germany

The locomotory system of animals has to cope with external and internal physical conditions confining and shaping the evolutionary space. This space can be probed by combining experimental observations with modelling supported by numerical simulations. To sustain locomotion animals are enforced to use oscillatory modes. In terrestrial locomotion this led to the development of legs in arthropods and vertebrates. Physical suitability combined with the requirement to enhance power and/or efficiency and to reduce or facilitate the control effort shape the space of solutions. We can show that gaits such as bipedal walking, grounded running, and running do represent an outcome of a compliant system being operated under different initial conditions. As nonlinear systems these systems inherit the property of attractive modes of operation which are used to reduce the control effort. During locomotion the legs as structural elements must fulfil their prescribed task efficiently. Segmentation of legs must prove itself with respect to this demand. The muscle as a common actuator is traded through evolution. Nevertheless, we start to understand that muscles seem to aggregate properties such as compliance, damping, and a geared output in a rather suitable and adaptable way. An integrative view covering the different levels of organization and the vast range of designs may help us to deduce general principles.

BP 27.2 Wed 14:30 ZEU 250

Learning Motor Skills with Information-Theoretic Approaches

— •Jan Peters[1,2], Christian Daniel[1], and Gerhard Neumann[1] — [1]Technische Universität Darmstadt — [2]Max Planck Institut für Intelligente Systeme

Synthesizing new motor skills from data has been a long standing vision of robotics, artificial intelligence, and the cognitive sciences. A first step towards this goal is to create approaches that can learn tasks triggered by environmental context or higher level instruction. However, learning techniques have yet to live up to this promise as only few methods manage to scale to high-dimensionality of humans and anthropomorphic robots. In this talk, we investigate a general framework suitable for learning motor skills in robotics and for explaining human movement learning which is based on the information-theoretic principles, such as movement organization, representation and acquisition by information entropy. As a result, the framework involves generating a representation of motor skills by parameterized motor primitive policies acting as building blocks of movement generation, and a learned task execution module that transforms these movements into motor commands. We discuss task-appropriate information-theoretic learning approaches for movements and illustrate their effectiveness on human movement data and in robot motor skill learning on both toy examples (e.g., paddling a ball, ball-in-a-cup) and on playing robot table tennis.

BP 27.3 Wed 14:45 ZEU 250

Humans run like pogosticks - with ankles

— •Horst-Moritz Maus[1], Shai Revzen[2], John Guckenheimer[3], Christian Ludwig[1], Johann Reger[4], and Andre Seyfarth[1] — [1]TU Darmstadt, Deutschland — [2]University of Michigan, Ann Arbor, USA — [3]Cornell University, Ithaca, USA — [4]TU Ilmenau, Deutschland

Running is an essential mode of human locomotion. Its large number of biomechanical and neural degrees of freedom are often modeled as a simple Spring Loaded Inverted Pendulum (SLIP). The SLIP body bounces as if on a pogo stick, pivoting on its spring leg and then jumping through a ballistic aerial phase. Updating SLIP model parameters to fit each step can result in trajectories that follow an observed path much more closely. These parameter updates represent a control input modulating the uncontrolled SLIP dynamics to obtain human-like movement and stability. Here we systematically construct a minimalistic *ankle-SLIP* model from measurements of humans running on a treadmill. Using Data Driven Floquet Analysis we identify candidate predictors for the parameter changes. Selecting a predictor related to ankle state allows us to predict running motion stride to stride and mimic rates of recovery from perturbation. We reveal inherent limitations in predictions made by other SLIP variants. Our methods produce a systematic means to search for prediction enhancing, yet low dimensional models of rhythmic processes in the physical sciences. More directly the "ankle-SLIP" models may impact gait assessment in sports and in clinical contexts and suggest control strategies for humanoid robots and prosthetic limbs.

BP 27.4 Wed 15:00 ZEU 250

Quantifying control effort of biological and technical movements: an information entropy based approach

— •Daniel Häufle[1,2], Michael Günther[1], Günter Wunner[2], and Syn Schmitt[1,3] — [1]Institut für Sport- und Bewegungswissenschaft, Universität Stuttgart, Germany — [2]Institut für Theoretische Physik 1, Universität Stuttgart, Germany — [3]Stuttgart Research Centre for Simulation Technology, Universität Stuttgart, Germany

In biomechanics and biorobotics muscles are often associated with reduced movement control effort compared to technical actuators. This is based on the notion that the muscle properties positively influence movement control and allow for simpler controllers. Other physical measures, such as energy consumption, stability, or jerk, have already be applied to compare such systems. However, previous definitions of control effort were based on system specific measures, such as voltages, forces, muscle activity, etc., which made it impossible to quantitatively compare the control effort of different actuation systems. Here, a system independent measure of control effort based on information entropy is presented. By calculating the Shannon information entropy of all sensor signals required for control, models of biological and technical control systems can be compared. Exemplarily applied to (biomechanical) models of hopping it reveals that the required information for controlling hopping is only $I = 32$bit with a muscle vs. $I = 660$bit with a DC-motor. This approach to control effort is thus applicable to and comparable across completely different actuators and control approaches.

BP 27.5 Wed 15:15 ZEU 250

COMPUTATIONAL MODEL FOR A FLEXIBLE SENSORIMOTOR MEMORY BASED ON A RECURRENT NEURAL NETWORK

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

The motor system has the unique capacity to learn complex movements in a flexible manner. Using recent recurrent network architecture based on the reservoir computing approach, we propose a computational model of a flexible sensorimotor memory for the storage of motor commands and sensory feedback into the synaptic weights of a neural network. The stored patterns can be retrieved, modulated, interpolated, and extrapolated by simple static commands. The network is trained in a manner that corresponds to a realistic exercising scenario, with experimentally measured muscular activations and with kinetic data representing proprioceptive feedback. The model may help to explain how complex movement patterns can be learned and then executed in a fluent and flexible manner without the need for detailed attention. Furthermore, it may help to understand the reafference principle in a new way, as an internal feedforward model for the prediction of expected sensory reafference would no longer be necessary. Instead, the reafference would be learned together with the motor commands by one and the same network, so that neural resources were exploited in a highly efficient way.

BP 27.6 Wed 15:30 ZEU 250

A COMPUTATIONAL MODEL EXPLAINS THE RELATIONSHIP BETWEEN MUSCULAR CO-ACTIVATION, REFLEXIVE CONTROL AND SELF-STABILITY

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

Sustaining stability during bipedal locomotion poses a challenge to the neuro-muscular-skeletal system, not only for the extremities but also for the spine. Commonly, a major role in maintaining stability is attributed to the reflex control system, which, however, is limited by the neural conduction velocity. For this reason, the concept of self-stability has been introduced, which claims that the mechanical properties of the muscular-skeletal system are exploited to maintain stability via muscular co-activation. Based on a computational model, we analyze the relationship between muscular co-activation, reflexive control and self-stability. The model includes pelvis, rib cage, and lumbar spine, as well as 90 Hill-type muscles, each endowed with a delayed monosynaptic reflex based on the lambda model. We show that muscular co-contraction not always increases the stability of the system, but rather that for a given reflex delay time there exists an optimal amount of co-contraction. These results may have an impact on the understanding of the motor control system in general, and in particular of the pathological reflex delay found in patients with low back pain.

BP 27.7 Wed 15:45 ZEU 250

How to turn the non-linear muscle into a linear all-purpose tool — •Karl Theodor Kalveram — Heinrich Heine Universität Düsseldorf, Germany — Technische Universität Darmstadt, Germany

The three basic categories of biologically motivated tasks that we discriminate we call "reaching", "cycling" and "enforcing". Because in all these activities the physical environment has to be influenced in a scaled manner, the organism must provide appropriately scaled forces. Our muscular-skeletal system solves those problems. We ascribe this to the organism's property to generate forces by muscular activation, and to generate this activation through neural stimulation. It remains, however, the open question, how to specify that stimulation, which exactly produces that forces, which are necessary to complete the respective task correctly?

Here we propose a control schema, which makes the non-linear Hill-type muscle a multiple-purpose tool for solving the biologically imposed motor tasks mentioned above. We achieve this by training an artificial neural network by a two-step auto-imitative learning algorithm (a special type of learning by regression), which makes the network an adaptive inverse controller of the physical environment to be controlled.

BP 27.8 Wed 16:00 ZEU 250

Computer simulation in biomechanics – past, present, future — •Hanns Ruder[1] and Syn Schmitt[2] — [1]Theoretische Astrophysik, Universität Tübingen — [2]Human Movement Simulation Lab, Universität Stuttgart

Since the beginning of science, humans wonder about, observe, and try to understand Nature. They do so by using the available tools and methods of their time to the best of their knowledge. In classical physics, over a century ago, research on the phenomena of life was common and driven by the desire to test the universality of physical laws. Already in 1906, Otto Fischer published theoretical considerations on studying the mechanics of human movement. Later, with the invention of computers, numerics helped researchers to solve more complex problems. It is now possible to study the birth and death of stars and the history of our universe. These new possibilities that come with Simulation technology are said to be the scientific paradigm of our age encouraging researchers from all disciplines to use these new methods. As physicists, we use reduced models to explore Nature and, for example in biomechanics, seek principles of human movement. We share the understanding that the very same forces which move the stars in the universe move the hips to let humans walk. Thus, computer simulations can help to understand the phenomena of human movement.

In this talk, we will discuss the organisation of biological material fulfilling the known principles of physics to walk, run, or jump. In short: from wobbling masses to intervertebral discs.