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A geometry- and muscle-based control architecture for synthesising biological movement. (English) Zbl 1460.92022

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Summary: A key problem for biological motor control is to establish a link between an idea of a movement and the generation of a set of muscle-stimulating signals that lead to the movement execution. The number of signals to generate is thereby larger than the body's mechanical degrees of freedom in which the idea of the movement may be easily expressed, as the movement is actually executed in this space. A mathematical formulation that provides a solving link is presented in this paper in the form of a layered, hierarchical control architecture. It is meant to synthesise a wide range of complex three-dimensional muscle-driven movements. The control architecture consists of a 'conceptional layer', where the movement is planned, a 'structural layer', where the muscles are stimulated, and between both an additional 'transformational layer', where the muscle-joint redundancy is resolved. We demonstrate the operativeness by simulating human stance and squatting in a three-dimensional digital human model (DHM). The DHM considers 20 angular DoFs and 36 Hill-type muscle-tendon units (MTUs) and is exposed to gravity, while its feet contact the ground via reversible stick-slip interactions. The control architecture continuously stimulates all MTUs ('structural layer') based on a high-level, torque-based task formulation within its 'conceptional layer'. Desired states of joint angles (postural plan) are fed to two mid-level joint controllers in the 'transformational layer'. The 'transformational layer' communicates with the biophysical structures in the 'structural layer' by providing direct MTU stimulation contributions and further input signals for low-level MTU controllers. Thereby, the redundancy of the MTU stimulations with respect to the joint angles is resolved, i.e. a link between plan and execution is established, by exploiting some properties of the biophysical structures modelled. The resulting joint torques generated by the MTUs via their moment arms are fed back to the conceptional layer, closing the high-level control loop. Within our mathematical formulations of the Jacobian matrix-based layer transformations, we identify the crucial information for the redundancy solution to be the muscle moment arms, the stiffness relations of muscle and tendon tissue within the muscle model, and the length-stimulation relation of the muscle activation dynamics. The present control architecture allows the straightforward feeding of conceptional movement task formulations to MTUs. With this approach, the problem of movement planning is eased, as solely the mechanical system has to be considered in the conceptional plan.

MSC:

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biomechanics; viscoelastic actuators; motor control; Jacobian; PID controller; upright stance; squat movement; morphological intelligence

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