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MOTION DYNAMICS AND OPTIMIZATION OF HUMANS AND A BIOLOGICALLY INSPIRED BIPED ROBOT

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ABSTRACT

In this talk, models, methods and results for numerical optimization of human motions will be discussed. Furthermore, a short overview of motion optimization of a biologically inspired biped robot will be given.

Both legged robots and humans consist of tree structured systems of joints and links. Classic legged robots are usually driven by one motor per joint; humans are driven by muscles, there are usually more than one or two muscles per joints and some muscles span more than one joint. Classical robots are designed to be as stiff as possible to simplify control, while the human motion apparatus shows a high amount of natural compliance.

Forward dynamics models of multibody systems like robots or the human motion apparatus consist of differential (algebraic) equations that compute the acceleration for each of the joints from the joint angles and velocities and the controls. The controls for legged robots can be e.g. motor torques, while for the biomechanical systems the controls are the muscle activations that (by additional models for the dynamics of muscle activation) lead to the force exertion.

A fixed motion goal for a robot may be realized by usually infinitely many joint angle trajectories, and for human motions, even a fixed joint angle trajectory may be realized by infinitely many muscle activation trajectories. These redundancies allow to chose from infinitely many possible motor torque resp. muscle activation trajectories for one specific motion or motion goal; optimization and optimal control (with an appropriate objective function like velocity, energy consumption or stability) are common ways to overcome and profit from these redundancies.

Solving optimal control problems for legged robot and human motion involves evaluation of the multibody system dynamics several times. The efficient Articulated Body Algorithm, which is adapted to the special (tree) structure of the systems is used. Efficient numerical optimal control techniques have been adapted to the problems and by using direct collocation (which discretizes both states and controls and therefore allows for solving the optimal control problem and integrating the differential equations of motion in one optimization problem) instead of widely used control parameterization approaches (which have to integrate the differential equations of motion several time to gain derivative information

that is needed for optimization), computation times for the biomechanical optimal control problems of human motion have been reduced by two orders of magnitude.

Results will be presented for optimal control of human kicking and jumping motions. Leg models with two resp. three rotational joints and five resp. nine muscle groups have been set up according to [3]. Detailed muscle models including the Hill-type force-velocity and force-length relations and differential equations for a rough model of the chemical processes that take place in the muscle, are taken into account. Muscle paths, i.e. the joint angle dependent lengths of the muscles and the resulting lever arms, are modeled and the overall torques resulting from all linear muscle forces are used in the forward dynamics model. The motions have been optimized in terms of analysis and prediction. For analysis, the objective function is chosen to be the difference between measured and computed motion; regularization terms like the sum of muscle activation squared may also be added. The computed muscle activations show good agreement with the measured EMG data. For prediction, the objective function is determined by the overall motion goal (e.g. time for a fast motion) and may also contain muscle activation (however, it is not clear yet, which objective function humans use). Here, the computed joint angle trajectories show good agreement with the measured motion data. Computation of a time optimal kicking motion for a time grid of 10 resp. 60 time points took 1.2 s resp. 6.3 s on a 1700+ Athlon XP. For the human kicking motion, the objective function that the human is supposed to apply when performing the motion, has been identified, both in terms of re-identification of computed motions and from measured motion data [4]; the outcome of this investigation now can be used to judge different heuristic objective functions for motion control of the central nervous system that are found in literature.

Furthermore, a short overview over the optimization of walking motions for a biologically inspired biped robot shall be given. Models of simple spring-mass robots can predict ground reaction forces of human walking [1], so it seems worthwhile to investigate an even more sophisticated robot with human-like leg kinematics. The robot has three joints in each of both legs with motors in the hips only. The motions of the knee and ankle joints result from springs that span the hip, knee and ankle, and from external excitation like ground contact. The motion of the hip is parameterized by a sinusoidal pattern generator, i.e. the parameters to be optimized are frequency, amplitude and offset. Furthermore, parameters of the muscle-like springs have been optimized. The computed motions are similar to those observed in real world experiments with this robot [2]. Walking motions both computed from the optimization and observed in real world experiments showed high robustness against disturbances from uneven terrain, even without any control besides joint angle control. With one fixed leg design, different walking, hopping or jogging motions can be realized.

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