Optimization based muscle wrapping in biomechanical multibody simulations

Johann Penner, Prof. Sigrid Leyendecker
University of Erlangen-Nuremberg

Biomechanical simulation based on multibody systems representing the skeleton and actuation by Hill-type muscle models is established as a major tool for investigating human motion. In addition to the activation level, typically, muscle models depend on the muscle length, contraction velocity and a force direction depending on the dynamics of the skeleton motion. In particular, the muscle force direction is influenced by the muscle path. The anatomical structure of the human body commonly forces muscles to wrap around obstacles such as bones and neighboring tissue, thus most muscle paths cannot be represented adequately as straight lines. Assuming that the muscles are always under tension, their path is often modelled as a locally length minimizing curve between their origin and insertion points [1].

This work is based on a mechanical analogue to find the shortest path on general smooth surfaces, using a discrete variational principle. In this context, the geodesic path is reinterpreted as the force-free motion of a particle in n dimensions, under holonomic constraints. The muscle path is then a G1-continuous combination of geodesics on adjacent obstacle surfaces. It can be described as a shortest path boundary value problem with G1-continuous transitions [1, 2, 3].

Using also discrete variational calculus to describe the dynamics [4] yields the advantage of a unified treatment for the complete musculoskeletal system. The resulting discrete Euler-Lagrange equations are a coupled equation system that can be solved for the skeleton and muscle path simultaneously. This is of particular importance in optimal control simulations, where inner optimizations for the muscle paths lead to very expensive computational costs and need to be avoided. In the given form, the formulation avoids such nested loops and is well suitable to be used in an optimal control framework based on a direct discretization technique for mechanical systems, known as DMOCC (Discrete mechanics and optimal control for constrained systems [5]).

References

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