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IMPLEMENTATION OF A 2D MUSCULOSKELETAL MODEL FOR THE ANALYSIS OF HUMAN MOVEMENT USING FULLY CARTESIAN COORDINATES

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Summary: Fully Cartesian Coordinates (FCC) formulation is a novel approach to analyze multibody systems [1] that joins the advantages of the Natural coordinates formulation, which defines all the segments of the model solely with the Cartesian coordinates of points and unit vectors [2], and the Cartesian coordinates formulation, which defines each rigid body independently of the remaining bodies of the system [3]. Hence, FCC formulation presents several computational advantages when applied in the analysis and simulation of complex systems, since the constraint equations are, at the most, quadratic, meaning that their contributions to the Jacobian matrix and right-hand side vectors of velocities and acceleration are either linear or even constant in certain circumstances. Moreover, FCC allows for an easier systematization of the modelling process [1], making this analysis approach particularly suitable for the study of biomechanical models. Nevertheless, the FCC formulation has not yet been applied to the kinematic and dynamic analysis of complex musculoskeletal models. This work addresses the computational and modelling aspects of the application of the FCC formulation to the inverse dynamic analysis of planar musculoskeletal biomechanical models where the calculation of the redundant muscle forces is required. A planar lower body musculoskeletal model composed of 6 segments was implemented using the FCC formulation. Each of the 14 lower leg musculotendon units was modeled as a Hill-type muscle model, with a rigid tendon, and integrated in the equations of motion of the system as a generalized external force. The computational muscle model parameters were linearly scaled from the anthropometric dimensions of the subject under analysis, and muscles' paths were defined using muscles' origin, insertion and via points. Muscle activations during the inverse dynamic analysis of five gait cycles, from one healthy subject were estimated by means of a static optimization in which the two cost functions presented respectively by Crowninshield & Brand [4] and by Rasmussen et al. [5], were used. An experimental protocol composed of 38 retroreflective markers [6], an infrared marker-based motion capture system and three force plates were used to acquire the kinematic and kinetic data. No problems were found regarding the modelling procedure and the convergence of the formulation for both the kinematic and dynamic analysis of movement with the inclusion of the redundant musculotendon units. The kinematic and dynamic results were similar to the ones reported in literature. Fully Cartesian Coordinates was successfully applied to analyze planar musculoskeletal biomechanical systems where the calculation of the redundant muscle forces is required. Since FCC combines the major advantages of the Natural and of the Cartesian coordinates formulations, it simplifies the description of the system topology, which increases the systematization of the modelling procedure and avoids coupled matrices. External forces and moments can also be easily applied to the system's elements. Hence, musculotendon units can be efficiently included in the equations of motion of the biomechanical system as external forces, in which the Hill-type muscle model is embedded. The value of these forces can be successfully calculated by means of static optimization procedures and physiological cost functions.