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STUDY OF THE FOOT-GROUND INTERFACE THROUGH AN MSD-FEM CO-SIMULATION APPROACH

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1 INTRODUCTION

Multibody System Dynamics (MSD) methodologies have been successfully used for performing Kinematic (KA), Forward (FDA) and Inverse Dynamic Analyses (IDA) of human movements, allowing the determination of the kinematics and dynamics of this complex system with relatively low computational effort. However, when the contact between surfaces of complex shapes is required, traditional contact models, utilized in MSD, tend to simplify contact surfaces into individual points or known geometrical shapes, limiting the completeness of the results [1]. Conversely, the Finite Element Method (FEM) is extremely prominent for highly detailed structural analysis, but it falls short when applied to dynamic systems due to the higher computational power required.

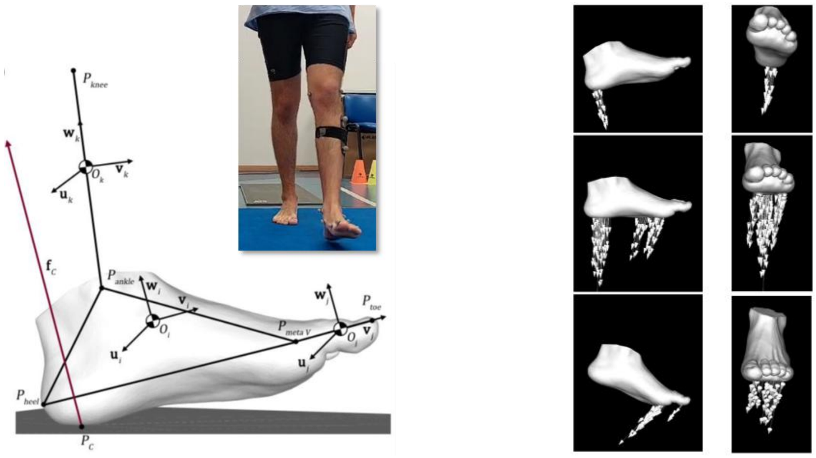
Given their complementary nature, the combination of these two formulations can lead to highly detailed and accurate results at significantly lower computational cost. Co-simulation methodologies between MSD and FEM are still very scarce, given its challenging implementation. Following the approach of a previous authors' work [2], the main objective of the present work is to develop a co-simulation computational methodology that combines MSD and FEM, and that allows for the study of the foot-ground interface and the detailed characterization of the contact between these complex geometries, with the accurate estimation of the resulting contact forces, contact points and pressure distribution. The obtained results were compared with corresponding experimental data.

2 METHODS

The proposed methodology combines an MSD formulation to describe the movement of the system with a FEM methodology to detect and manage the contact phenomenon. For the MSD system, a fully Cartesian coordinates formulation with a generic rigid body (FCC-GRB) [3] was adopted to deal with the kinematics and dynamics of the gait stride, and on the FEM side, a nonlinear and nonsmooth finite element software [4] was employed that performs the contact detection and subsequent determination of contact forces and points. Four-node tetrahedra (FEM-TET4) and a compressible neo-Hookean material model were considered for defining the foot model (with $E = 3.62\ MPa$ and $\nu = 0.3$ estimated experimentally). A continuum contact model based on a novel approximate distance function was used for the contact detection and computation of the corresponding gap, while frictional forces were determined by means of a simplified Coulomb friction model [4].

The communication between the two methodologies follows the gluing algorithm proposed by Hulbert and colleagues [5], i.e., in every time step of the analysis, the MSD software provides the relative position of the different bodies to the FEM software, the FEM software performs contact detection and returns to the MSD software the corresponding contact forces and their respective application points. On the MSD side, these contact forces are transformed into generalized forces and assembled in the system's equations of motion that, when solved, provide the state of the system to the FEM software for the contact detection and management of the next analysis step.

The experimental data necessary to perform the IDA was acquired at Laboratório de Biomecânica de Lisboa at Instituto Superior Técnico, and it refers to a healthy 23-year-old male, weighing 63.4 kg. Kinematic and kinetic data regarding the gait cycle were recorded using a marker-based MOCAP system composed of 14 Qualisys ProReflex 1000 infrared cameras, three AMTI OR 6–7 force plates, and one RSScan 1m Footscan pressure plate. Results presented below.



(a) (b)

Figure 1 – (a) Experimental protocol and multibody model; (b) FEM model w/ contact forces and application points.

3 Discussion and Conclusions

An MSD-FEM co-simulation methodology was presented where the combination of the multibody formulation, in handling the global kinematics and kinetics of the entire system, with the detailed accounting of contact between bodies provided by FEM, resulted in a successful strategy. When simulating foot-ground contact, the developed approach provided satisfactory results, suggesting that the developed methodology can be also utilized in the analysis of the contact between the human body and other complex systems such as orthotics and exoskeletons.

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