P054 - Evaluation of ground reaction forces by inverse dynamics analysis.

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1. INTRODUCTION

The inverse dynamics simulation of the musculoskeletal system is a common method to analyse human motion.

To obtain the ground reaction forces (GRF), measuring them experimentally provides accurate results. However, the number of steps is limited to the number of force platforms available in the lab. Several numerical methods have been proposed to compute the GRF using a model of the foot. Compliant models use simple equations, but the estimation of the local contact compliance can be hard to achieve. Rigid models usually require a priori information about the gait cycle.

2. RESEARCH QUESTION

The purpose of this work is to provide an efficient method, using a simple rigid and unilaterally constrained model of the foot to compute the GRF without a priori information on the gait cycle. Hence, the model of the foot does not require any data related with the compliance of the foot-ground contact and is kept as simple as possible.

3. METHOD

The equations of motion of a multibody system with bilateral and frictionless unilateral constraints can be written, as [1]:

$$\begin{cases} \mathbf{M}(\mathbf{q})\ddot{\mathbf{q}}(t) + \mathbf{g}_{\mathbf{q}}^{\mathrm{T}}(\mathbf{q})\boldsymbol{\lambda} - \boldsymbol{f}(t) = \mathbf{0} & (1) \\ \mathbf{g}^{B}(\mathbf{q}) = \mathbf{0} & (2) \\ \mathbf{0} \leq \mathbf{g}^{U} \perp \boldsymbol{\lambda}^{U} \geq \mathbf{0} & (3) \end{cases}$$

where $\mathbf{g}^{\mathrm{T}} = [\mathbf{g}^{B,\mathrm{T}}, \mathbf{g}^{U,\mathrm{T}}]$ and $\boldsymbol{\lambda}^{\mathrm{T}} = [\boldsymbol{\lambda}^{B,\mathrm{T}}, \boldsymbol{\lambda}^{U,\mathrm{T}}]$, $\mathbf{M}(\mathbf{q})$ is the mass matrix, $\mathbf{q}$, $\dot{\mathbf{q}}$ and $\ddot{\mathbf{q}}$ are respectively the coordinates, velocities and accelerations vectors, $\mathbf{g}^{B}(\mathbf{q})$ and $\mathbf{g}_{\mathbf{q}}^{B}$ represent the bilateral kinematic constraints and the corresponding gradient, $\boldsymbol{\lambda}^{B}$ denotes the Lagrange multipliers containing internal efforts, $\mathbf{g}^{U}$ and $\mathbf{g}_{\mathbf{q}}^{U}$ represent the unilateral constraints between the feet and the ground and their gradient, and $f(t)$ is the vector of external forces, including the gravity forces.

The GRF are treated as the set of unilateral reactions forces represented by the Lagrange multipliers $\boldsymbol{\lambda}^{U}$.

Eq. (1) is the dynamic equilibrium of the system, and Eq. (2) represents the constraints which model the kinematic joints and the rigid body conditions. Eq. (3) express the fact that, if a constraint is activated ($\mathbf{g}_j^U(\mathbf{q}) = \mathbf{0}$) then the reaction force must be positive ($\boldsymbol{\lambda}_j^U \geq \mathbf{0}$) and conversely, if a gap is measured ($\mathbf{g}_j^U(\mathbf{q}) > \mathbf{0}$), the reaction force must be null ($\boldsymbol{\lambda}_j^U = \mathbf{0}$). This model can be extended to account for friction forces.

The values of $\mathbf{q}$ and $\ddot{\mathbf{q}}$ are measured experimentally during a gait test at the Laboratory of Human Motion Analysis of the University of Liège. Based on these kinematic data, our goal is to evaluate the unknown reaction forces $\boldsymbol{\lambda}$. The method relies on the identification of the active unilateral constraints and on a least-square inversion of Eq. (1).

4. RESULTS

Figure 1 compares the vertical ground reaction forces obtained using the proposed approach and the force platforms.

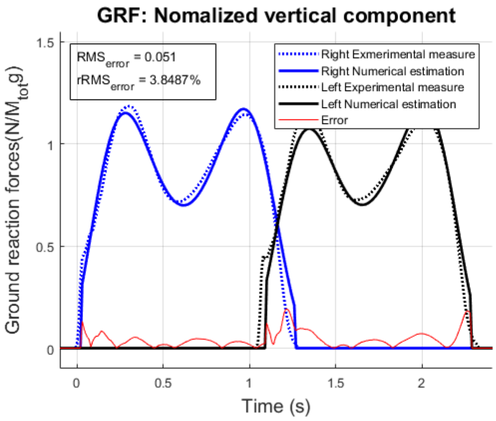

Fig. 1: Ground reaction forces

5. DISCUSSION

Based on 30 gait tests, performed by four healthy male subjects walking at a comfortable speed, the relative RMSE is 4.1% for the vertical component, 9.4% for the anterior component and 4.6% for the moment in the sagittal plane.
The proposed method produces reliable results in a healthy gait test. Future work will address other cases, like pathological gait, running or jumps.

Reference:

[1]: B. Brogliato, Nonsmooth mechanics, 1999.