Rigid foot/ground contact model for inverse dynamic analysis solely based on kinematic data.

1. INTRODUCTION

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

Measuring the ground reaction forces experimentally using force platforms is an accurate method to estimate them. However, the number of steps is limited by the number of force platforms available in the lab. Several numerical methods have been proposed to estimate the ground reaction forces without force platforms, i.e. solely based on kinematic data combined with a model of the foot-ground contact [1].

The purpose of this work is to provide a more efficient method, using a simple rigid and unilaterally constrained model of the foot to compute the ground reaction forces. This way, 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.

2. **METHOD**

The equations of motion of a multibody system can be written, as [2]:

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

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 idea is to treat the ground reaction (i.e. the contact forces) 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) represents a complementarity condition: if a constraint is activated ($\mathbf{g}_{j}^{U}(\mathbf{q}) = \mathbf{0}$) then the reaction force must be positive ($\boldsymbol{\lambda}_{j}^{U} \geq \mathbf{0}$). Conversely, if a gap is measured ($\mathbf{g}_{j}^{U}(\mathbf{q}) > \mathbf{0}$), the reaction force must be null ($\boldsymbol{\lambda}_{j}^{U} = \mathbf{0}$).

The values of $\mathbf{q}$, $\dot{\mathbf{q}}$ and $\ddot{\mathbf{q}}$ are measured experimentally during a gait test at the Laboratory of Human Motion Analysis of the University of Liège, using optoelectronic cameras and signal processing methods. 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).

3. RESULTS AND DISCUSSION

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

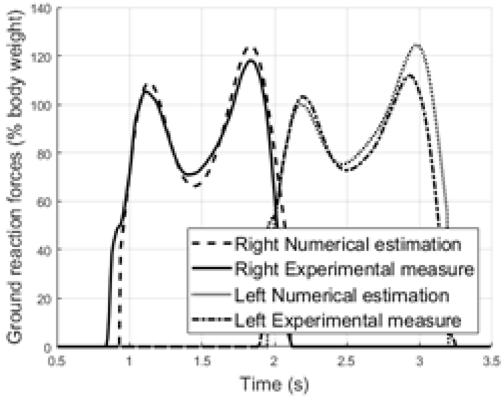

Fig. 1: Ground reaction forces

The proposed method produces encouraging results in a healthy gait test. Future work will address other cases, like pathological gait, running or jumps.

References

2. Brüls, O. et al., Computer methods in applied mechanics and engineering, 281:131-161, 2014.