Evaluation of ground reaction forces based on kinematic data

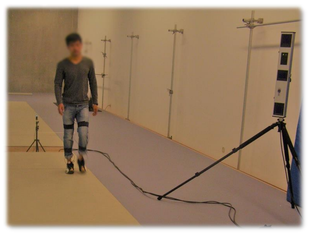
R. Van Hulle, C. Schwartz, O. Brüls
Laboratory of Human Motion Analysis, University of Liège, Belgium

Usual evaluation of foot contact forces in motion analysis

Experimental measurement: force platform

Advantages: reliable results

Flaws: number of steps limited by the number of force plates



Numerical estimation

Advantages: number of steps only limited by the motion capture range

Flaws: available models require data related to the compliance between the foot and the ground

$$\mathbf{F_R} = f \sum_{i=1}^{N_s} m_i(\ddot{\mathbf{x}}_\mathbf{i} - \mathbf{g})$$

$$\mathbf{F_L} = (1-f) \sum_{i=1}^{N_s} m_i(\ddot{\mathbf{x}}_\mathbf{i} - \mathbf{g})$$

Objective

Develop a general numerical method able to deal with multiple contact points

Methods

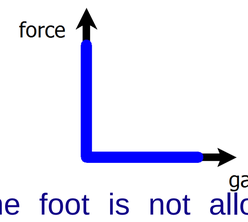
Biomechanical model → Adding unilateral constraints → Constrained Equations of Motion → Determination of contact status → Solving Equations of Motion

Biomechanical model

$$\begin{cases} \mathbf{M}\ddot{\mathbf{q}}(t) + \mathbf{g}_\mathbf{q}^{\boldsymbol{B},T}(\mathbf{q})\boldsymbol{\lambda}^{\boldsymbol{B}} - \boldsymbol{f}(\mathbf{q}) = \mathbf{0} \\ \mathbf{g}^{\boldsymbol{B}}(\mathbf{q}) = \mathbf{0} \end{cases}$$

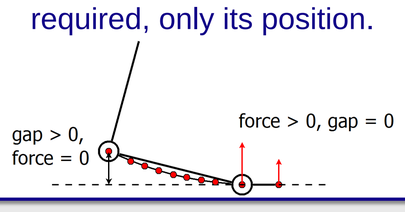
$\mathbf{M}$, the mass matrix;
$\mathbf{q}$, the coordinates;
$\mathbf{g}^{\boldsymbol{B}}$, the bilateral constraints;
$\boldsymbol{\lambda}^{\boldsymbol{B}}$, the Lagrange multipliers associated to the bilateral constraints;
$\boldsymbol{f}$, the external forces.

Adding unilateral constraints



The foot is not allowed to penetrate the ground.

No information on the compliance of the foot is required, only its position.

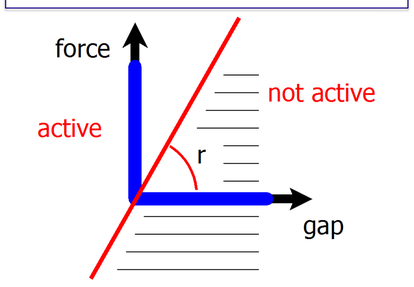


Constrained Equations of Motion

$$\begin{cases} \mathbf{M}\ddot{\mathbf{q}}(t) + \mathbf{g}_\mathbf{q}^{\boldsymbol{B},\mathrm{T}}(\mathbf{q})\boldsymbol{\lambda}^{\boldsymbol{B}} + \mathbf{g}_\mathbf{q}^{\boldsymbol{U},\mathrm{T}}(\mathbf{q})\boldsymbol{\lambda}^{\boldsymbol{U}} - \boldsymbol{f}(\mathbf{q}) = \mathbf{0} \\ \mathbf{g}^{\boldsymbol{B}}(\mathbf{q}) = \mathbf{0} \\ \mathbf{0} \le \mathbf{g}^{\mathbf{U}} \perp \boldsymbol{\lambda}^{\mathbf{U}} \ge \mathbf{0} \end{cases}$$

$\mathbf{g}^{\boldsymbol{U}}$, the unilateral constraints;
$\boldsymbol{\lambda}^{\boldsymbol{U}}$, the Lagrange multipliers associated with the unilateral constraints.

Determination of contact status



Criterion based on penetration and estimated contact force.

Solving Equations of Motion

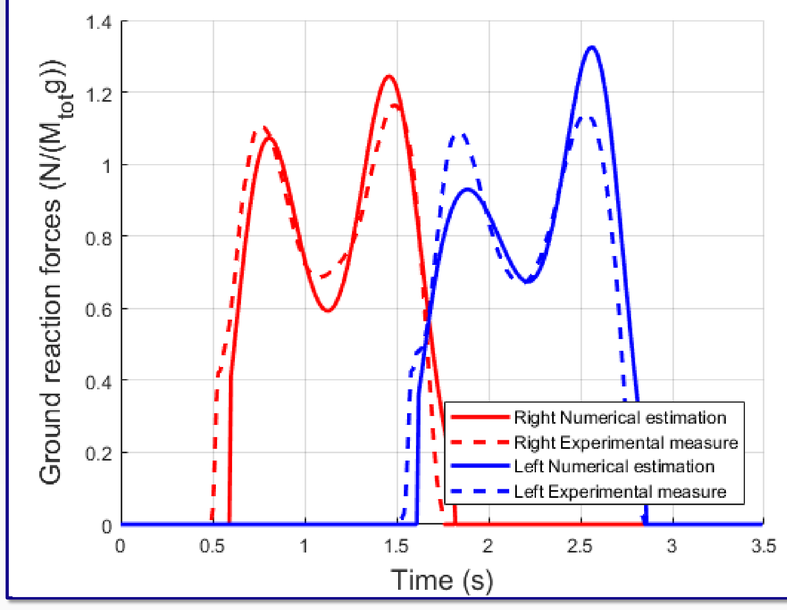
The problem might be under- or overdeterminated depending on the number of active contact points.

The indetermination is handled using the Least-square Method.

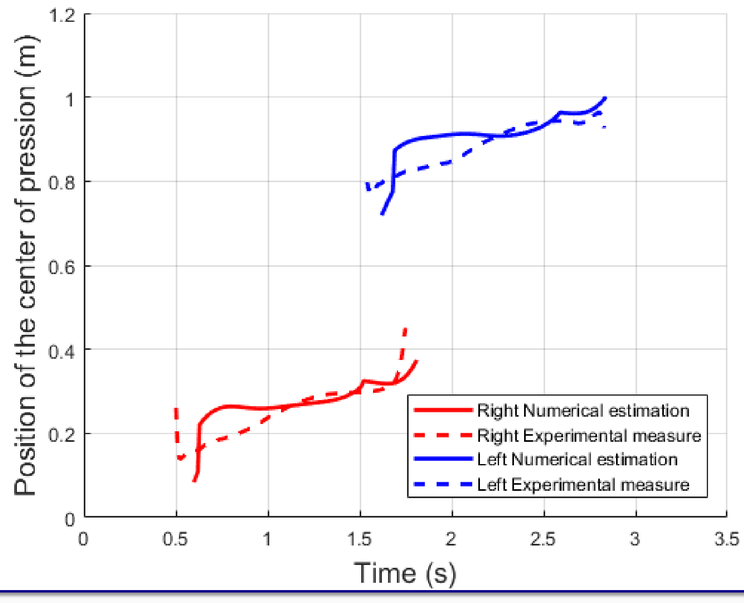
$\boldsymbol{\lambda}^{\mathbf{U}}$ gives the ground reaction forces.

Results

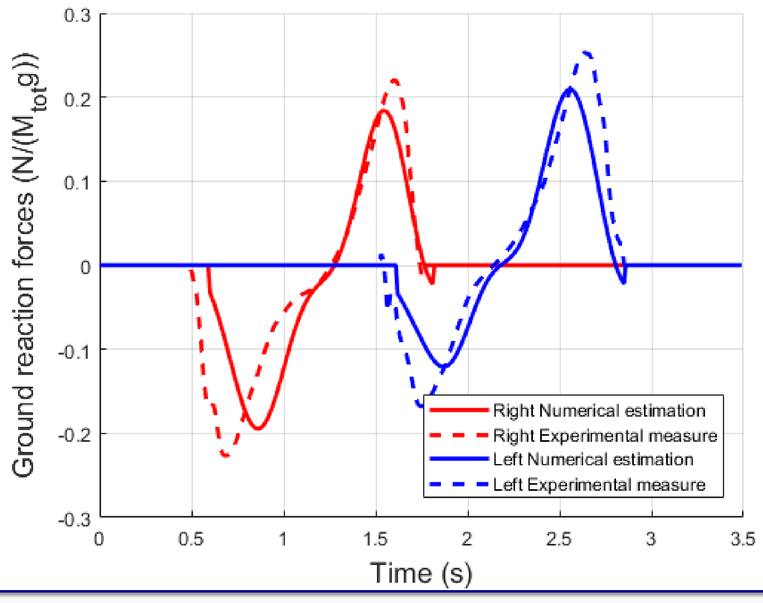
Gound reaction force: vertical component



Position of the center of pressure



Gound reaction force: fore-aft component



Conclusion

Preliminary but encouraging results

Easy to implement: no information on the compliance is required, only kinematic and geometric data

General method for multiple contact points: healthy and pathological gait, running, threadmill, jumping, etc.

University of Liège, Belgium
Aerospace & Mechanical Engineering Department
Multibody and Mechatronic Systems - www.ltas-mms.ulg.ac.be

University of Liège, Belgium
Faculty of Applied Sciences, Faculty of Medecine
LAMH - http://labos.ulg.ac.be/lamh/

Contact: Romain Van Hulle, ✉ romain.vanhulle@ulg.ac.be, ☎ +32 4 366 91 13