

EVALUATION OF THE CONTACT FORCE BETWEEN TWO RIGID BODIES USING KINEMATICS DATA ONLY

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Introduction

In many studies in the biomechanical field, the contact forces between the ground and the foot of the subject is of great importance. These forces can be experimentally measured or numerically computed.

The experimental way gives reliable results, but the number of measured steps remains frequently limited by the number of available force plates.

On the other hand, the global acceleration of the body can be used to calculate the global reaction force¹. However, this method has limitations when multiple contact points are recorded or when the gait is atypical. The method proposed here is a more general method and is only based on the kinematics data, while remaining simple to implement.

Methods

In general, the equations of motion of a multibody system can be written as

$$\begin{cases} \mathbf{M}\ddot{\mathbf{q}}(t) + \mathbf{g}_q^{B,T}(\mathbf{q})\lambda^B - \mathbf{f}^*(t) = \mathbf{0} \\ \mathbf{g}^B(\mathbf{q}) = \mathbf{0} \end{cases} \quad (1)$$

where \mathbf{M} is the mass matrix, the vector \mathbf{q} , $\dot{\mathbf{q}}$ and $\ddot{\mathbf{q}}$ are respectively the coordinates, velocity and acceleration vectors. $\mathbf{g}^B(\mathbf{q})$ represents the bilateral kinematic constraints, and $\mathbf{g}_q^{B,T}(\mathbf{q})$ the associated constraint gradient. λ^B express the Lagrange multipliers, including internal efforts. Finally, $\mathbf{f}^*(t)$ is the vector of external forces, containing among other the reaction forces caused by contact conditions.

The idea is to eliminate the ground reaction forces from the external forces vector which leads to the force vector $\mathbf{f}(t)$ and to treat the ground/foot contact condition as a set of unilateral constraints $\mathbf{g}^U \geq \mathbf{0}$. The contact is assumed to occur between rigid bodies without any local compliance and the ground reaction forces are then represented by an additional set of Lagrange multipliers λ^U .

The unilateral constraints are activated only when the contact between the feet and the ground is established. The equations of motion become²:

$$\begin{cases} \mathbf{M}\ddot{\mathbf{q}}(t) + \mathbf{g}_q^T(\mathbf{q})\lambda - \mathbf{f}(t) = \mathbf{0} \\ \mathbf{g}^B(\mathbf{q}) = \mathbf{0} \\ \mathbf{0} \leq \mathbf{g}^U \perp \lambda^U \geq \mathbf{0} \end{cases} \quad (2)$$

where $\mathbf{g}^T = [\mathbf{g}^{B,T}, \mathbf{g}^{U,T}]$ and $\lambda^T = [\lambda^{B,T}, \lambda^{U,T}]$.

Results

The value of \mathbf{q} , $\dot{\mathbf{q}}$ and $\ddot{\mathbf{q}}$ are obtained from experimental data and using standard signal processing methods. Then a numerical algorithm is developed to solve Eq. (2) for the unknowns λ .

Figure 1 shows the vertical ground reaction forces obtained using a force plate and numerically using the proposed approach.

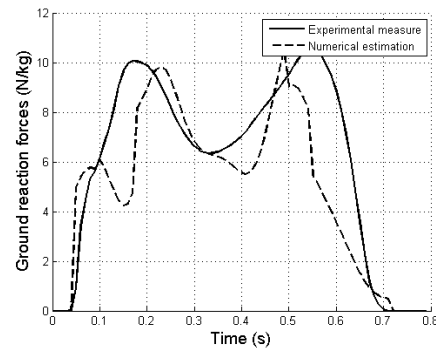


Figure 1: Ground reaction forces.

Discussion

This method produces preliminary but encouraging results. Easy to implement, it should contribute to estimate the ground reaction force in many cases: healthy and pathological gait, running, treadmill, etc.

In future work, the model will be improved in order to obtain exploitable results for the ground reaction forces along the vertical, lateral and longitudinal axis as well as the position of the center of pressure during various types of gait.

References

1. Koopman, B. et al., Journal of Biomechanics, 28:1369-1376, 1995.
2. Brüls, O. et al, Computer methods in applied mechanics and engineering, 281:131-161, 2014.

