**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: Koopman’s method**  
Advantages: easy to implement  
Flaws: single contact point foot model, approximation when atypical/pathological gait

---

**Objective**

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

---

**Methods**

**Simple Equations of Motion**

\[
\begin{align*}
M \ddot{q} + g^B(q) + \sum_i \lambda_i^B \frac{\partial g_i^B}{\partial \dot{q}} &= \mathbf{f} \\
g^B(q) &= 0
\end{align*}
\]

\(M\), the mass matrix;  
\(q\), the coordinates;  
\(g^B\), the bilateral constraints;  
\(\lambda_i^B\), the Lagrange multipliers associated to the bilateral constraints;  
\(f\), the external forces.

The foot is not allowed to penetrate the ground.  
No information on the compliance of the foot is required, only its position.

---

**Adding unilateral constraints**

\[
\begin{align*}
M \ddot{q} + g^U(q) + \sum_i \lambda_i^U \frac{\partial g_i^U}{\partial \dot{q}} &= \mathbf{f} \\
g^U(q) &= 0
\end{align*}
\]

\(g^U\), the unilateral constraints;  
\(\lambda_i^U\), the Lagrange multipliers associated with the unilateral constraints.

Criterion based on penetration and estimated contact force.

\(\lambda^U\) gives the ground reaction forces.

---

**New Equations of Motion**

\[
\begin{align*}
M \ddot{q} + g^B(q) + \sum_i \lambda_i^B \frac{\partial g_i^B}{\partial \dot{q}} &= \mathbf{f} \\
g^B(q) &= 0
\end{align*}
\]

\[
\begin{align*}
M \ddot{q} + g^U(q) + \sum_i \lambda_i^U \frac{\partial g_i^U}{\partial \dot{q}} &= \mathbf{f} \\
g^U(q) &= 0
\end{align*}
\]

The problem might be under- or overdetermined depending on the number of active contact points.  
The indetermination is handled using the Least-square Method.

---

**Determination of contact status**

**Solving Equations of Motion**

**Results**

**Ground reaction force: vertical component**

**Position of the centre of pressure**

**Ground 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, etc.