# ESTIMATING THE COMPLETE GROUND REACTION FORCES AND MOMENTS DURING WALKING USING INERTIAL MOTION CAPTURE

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## ABSTRACT

Whole-body inverse dynamics techniques have been recently proposed to assess the ground reaction forces and moments (GRF&M) only from motion data. Even though such techniques remove the dependency on force plate measurements, they are still bounded by the restrictions imposed by optical motion capture, i.e. the limited marker tracking volume, increased complexity, and requirement of a laboratory space. As a result, GRF&M prediction techniques cannot be applied in ambulatory environments, outside the lab. To tackle this limitation, we propose a method to estimate the GRF&M using only Xsens MVN, a robust ambulatory motion capture system consisted of 17 inertial measurement units [1].

A custom-made program was developed, in which the Newton-Euler equations of motion were used to predict the total external forces and moments, which, during single stance, balances the GRF&M applied on the foot in contact with the ground. However, during double stance the equations of motion result in the sum of left & right GRF&M, and we therefore use a smooth transition assumption to distribute this sum between both feet [2].

To evaluate our method, we measured 11 healthy subjects, recording simultaneously using the Xsens MVN system and AMTI force plates. The accuracy of our GRF&M estimates versus the force plate measurements was assessed using Pearson correlation coefficient ($\rho$) and relative root mean square error (rRMSE).

The results showed excellent correlation coefficients and low to moderate rRMSE for the vertical ($\rho$=0.99, rRMSE=5.9±3.1%), anterior: ($\rho$=0.95, rRMSE=8.0±2.0%), and sagittal: ($\rho$=0.90, rRMSE=14.9±3.84%) GRF&M. Strong correlations and moderate to high rRMSE were observed in the other three components (lateral: $\rho$=0.85, rRMSE=15.2±4.7%, frontal: $\rho$=0.73, rRMSE=40.2±18.6%, transverse: $\rho$=0.85, rRMSE =21.0±6.4 %).

To our knowledge, this study was the first to estimate GRF&M using a technique based on inertial measurement units. Since force measurements are usually impractical outside the lab, the use of inertial motion capture increases the value of motion-based GRF&M estimation. Moreover, the performance was comparable to optical motion capture-based estimates, reported in previous studies. Future work should investigate the suitability of this method in assessing GRF&M and joint loading in daily life, clinical and sport applications.

## REFERENCES

[1] D. Roetenberg, H. Luinge, and P. Slycke, "Xsens MVN : Full 6DOF Human Motion Tracking Using Miniature Inertial Sensors," no. July 2015, pp. 1–9, 2013.
[2] L. Ren, R. K. Jones, and D. Howard, "Whole body inverse dynamics over a complete gait cycle based only on measured kinematics," *J. Biomech.*, vol. 41, no. 12, pp. 2750–2759, 2008.