Inertial Compensation in Moving Force Plates

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Introduction

Instrumented treadmills provide a convenient environment for inverse dynamic gait analysis. Load cells underneath each force plate measure the ground reaction forces (GRF) as test subjects walk across the treadmill.

Recently, instrumented treadmills are equipped with the ability to rotate and translate the walking surface. However, moving the platform causes inertial artifacts in the measured GRF. Consequently, inverse dynamics is no longer possible and a compensation method is required in order to obtain accurate GRF measurements.

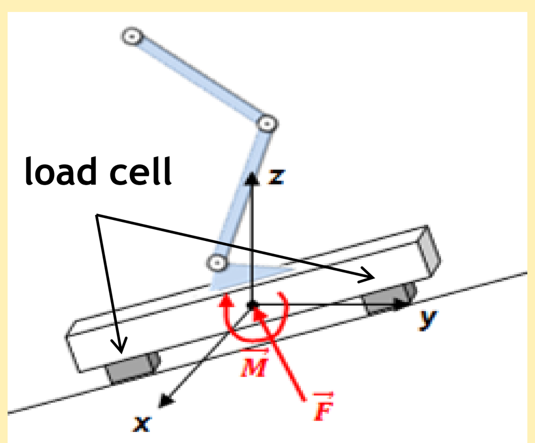


Figure 1. Load cells are located underneath both the test subject and the force plate. Inertial errors in ground reaction forces occur when load cells cannot distinguish between the force exhibited by the test subject and the inertia created when the large platform mass is moved

Methods

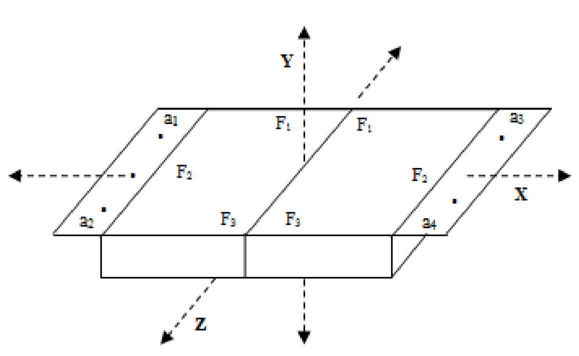
Mathematical Model

3D forces (*F*) and moments (*M*) generated by inertia and gravity are linearly related to accelerometer signals (*s*), where coefficient matrix *C* contains the mass properties.

$$\begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = C_{6\times 13} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \\ \vdots \\ s_{12} \\ 1 \end{bmatrix} \;\Rightarrow\; \boldsymbol{G} = \boldsymbol{C} \cdot \boldsymbol{s}$$

Instrumentation

- 2 DOF platform motion
  - *-mediolateral translation*
  - *-sagittal pitch*



- 4 triaxial accelerometers mounted on the corners of the rigid treadmill platform
- random signals used to move the treadmill while forces and accelerations are recorded

Procedure

Estimate ***C*** from an unloaded trial with random movements

$$\boldsymbol{C} = argmin_C \sum_i \|\boldsymbol{G}_i - \boldsymbol{C}\cdot \boldsymbol{s}_i\|^2$$

↓

Record force and acceleration from a trial with different movements

↓

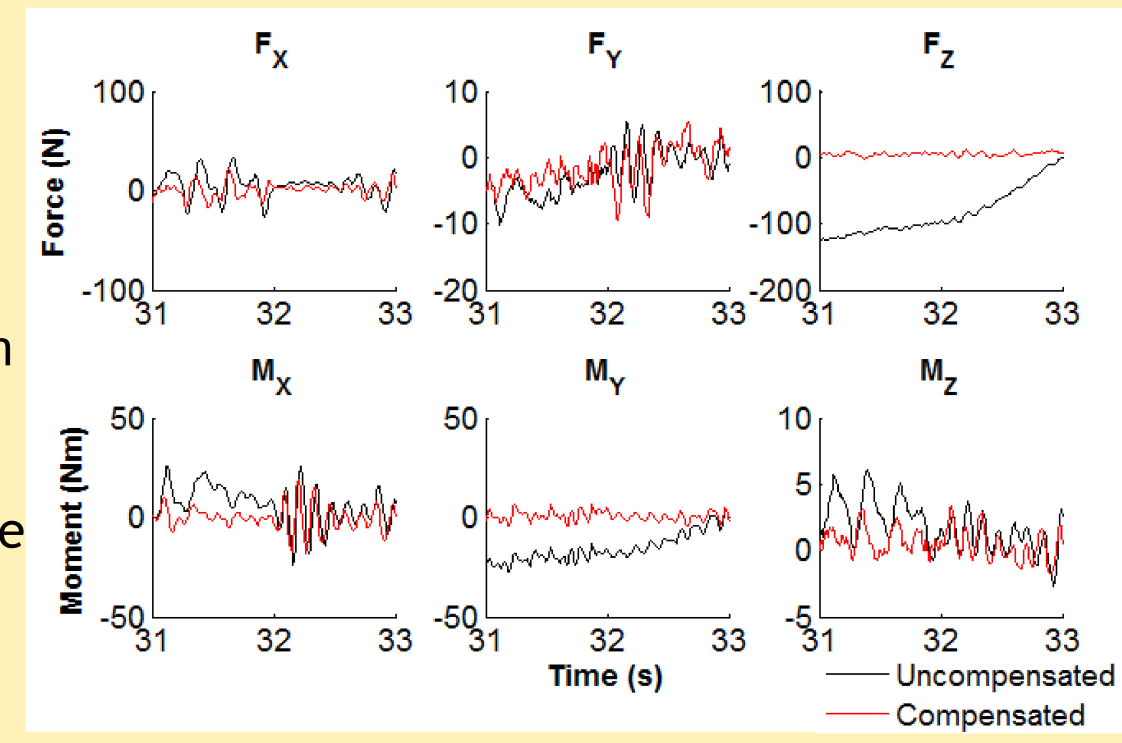
Mass calibration coefficients ***C*** compensate for the inertial effects during the other trial

$$\boldsymbol{G}_{corrected} = \boldsymbol{G} - \boldsymbol{C}\cdot \boldsymbol{s}$$

Results

Preliminary results indicate an average reduction of 76.76% and 45.61% in the root mean square (RMS) of force and moment signals. RMS closest to zero is ideal.

Figure 2. Uncompensated (black) and compensated (red) force signals. obtained from applying calibration coefficients from a trial containing dissimilar random movements. The RMS reduction of each signal is indicated.



Uncompensated and compensated forces from a moving trial were added to a standard walking trial without platform movement. Results indicate that the compensation method is capable of significantly reducing errors in joint moment calculations that occur when the treadmill platform is moving.

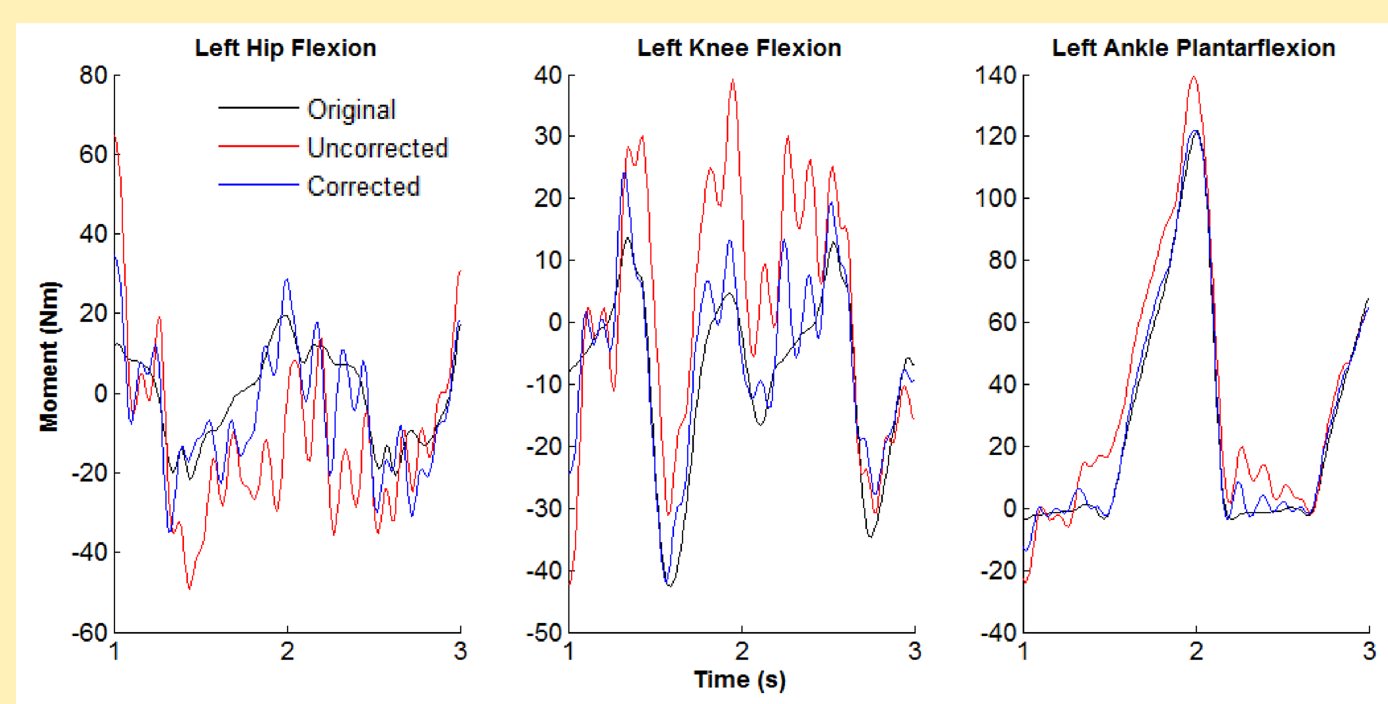


Figure 3. Original (black), uncorrected (red), and corrected (blue) joint moments. Errors in hip flexion are reduced from 45% to 17% by implementing the compensation method. The 10% and 20% error in knee and ankle flexion were reduced to 1% and 2%, respectively.

Limitations

- Method is dependent on the rigid body model assumption
- Accelerometer sensitivity affect the results
- Influenced by the cutoff frequency of the low-pass filter

Conclusion

- Capable of reducing inertial artifacts to a more acceptable level
- Errors in joint moment calculations (hip, knee, ankle) can be significantly reduced
- Simple and easy to implement
- Can be used for any application with a moving force plate

References

1. Pagnacco G, et al. *Biomed Sci Instrum*; 36: 397-402, 2000.
2. Berme N, et al. U.S. Patent 8.315.822 B2.

Acknowledgment

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