INERTIAL COMPENSATION IN MOVING FORCE PLATES

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INTRODUCTION

Instrumented treadmills provide a convenient environment for inverse dynamic gait analysis. Recently, treadmills have become available with the capability to rotate and translate the walking surface. However, acceleration and tilt of a force plate introduces inertial and gravitational artifacts in the ground reaction forces (GRF). Consequently, inverse dynamic analysis is no longer possible. Previously proposed methods to compensate for these errors were either limited to 1 degree-of-freedom (DOF) motion [1] or required complex instrumentation and analysis [2]. Here, we present a simple linear, accelerometer-based compensation method for inertial compensation of force plate data.

METHODS

In an ideal rigid body, the 3D force and moment generated by inertia and gravity are linearly related to accelerometer signals. If force and moment are combined into a vector g, and vector s is defined as the set of accelerometer signals, augmented with a one to represent a constant term, the linear model is:

$$\mathbf{g} = \mathbf{Cs}$$

where **C** is a coefficient matrix that represents the mass properties. When **C** is known, the expression on the right hand side can be used to estimate GRF artifacts from accelerometer signals. These artifacts can then be subtracted from measured GRF data before inverse dynamic gait analysis is performed.

Our method was tested on a split-belt instrumented treadmill (VG005-A, Motek Medical, Amsterdam, Netherlands) capable of 2-DOF platform movement (mediolateral translation and sagittal pitch). Four triaxial accelerometers (Delsys Trigno) were placed on the corners of the treadmill frame. GRF and accelerometer signals were recorded during trials of unloaded treadmill movement. GRF data (3D force and moment) were filtered by a single-pass, 2nd-order Butterworth filter with a 6Hz cutoff frequency.

The 6x13 coefficient matrix C was estimated from a 60-second white noise movement trial in which the treadmill surface was both translated and rotated. This calibration was then applied to the force signals of a different white noise trial. Effectiveness of the inertial compensation was quantified by the root-mean-square (RMS) of the uncompensated and compensated signals. As the treadmill surface is unloaded, it is known that the true value of GRF must be zero.

RESULTS AND DISCUSSION

Preliminary results indicate an average reduction of 76.76% and 45.61% in force and moment signals of the unloaded force plate (Table 1, Figure 1). Remaining errors in force signals may be attributed to insufficiently smooth treadmill movements, which may excite the flexible modes and violate the rigid body model assumption.

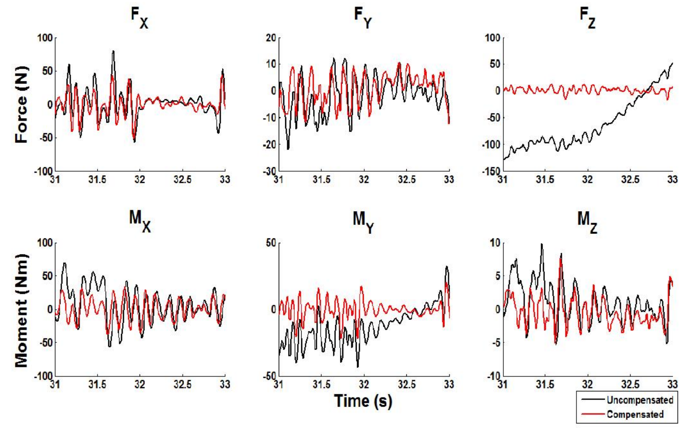

Figure 1: Uncompensated (black) and compensated (red) force signals obtained from calibration coefficients of a dissimilar white noise treadmill movements.

Table 1: RMS values of uncompensated and compensated 3D force and moment signals, with the percentage of reduction.

	Force Signal RMS		
Signal	*Uncompensated*	*Compensated*	*% Reduction*
F_{xyz} *(N)*	69.83	16.23	76.76
M_{xyz} *(Nm)*	32.36	17.60	45.61

Mass coefficients **C** should be determined from a calibration trial in which treadmill movements are most similar to the trial that requires the compensation. For example, a calibration determined from rotational movements would poorly compensate a trial containing pure translational movement.

The described method is general and compensation for full 6-DOF motion is possible with the four accelerometers. After compensation, an additional coordinate transformation is needed to register the force plate data with the non-moving global coordinate system.

CONCLUSIONS

Our method is capable of reducing inertial artifacts in the GRF measured by moving force plates, thereby allowing greater accuracy of joint moment calculations through traditional inverse dynamics.

REFERENCES

1. Pagnacco G, et al. Inertially compensated force plate: a means for quantifying subject's ground reaction forces in non-inertial conditions. *Biomed Sci Instrum*; 36: 397-402, 2000.
2. Berme N, et al. Force measurement system having inertial compensation. U.S. Patent 8.315.822 B2.