Application of automatic segment filtering procedure to the kinematics of running

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Introduction

The processing techniques used on biomechanical signals can often be as important as the experimental paradigms. The filtering methods of motion capture signals have received considerable attention with respect to estimating signal derivatives in particular. Recently, an automatic filtering procedure which applies a Butterworth low-pass filter with different cut-off frequencies specific to signal sections was proposed [1]. This technique aimed to better filter time-series signals with varying frequency content. It is not clear, however, how this approach would compare to typical filtering procedures when applied to a set of common biomechanical measures which comprise multiple signals. Therefore, the purpose of this investigation was to explore the application of the automatic segment filtering procedure (ASFP) to a publicly available simulated running stride [2].

Methods

The test data of van den Bogert & de Koning (1996) were used as criterion data [2]. This data set consists of lower body segment kinematics and ground reaction forces from computer simulations of running gait. To illustrate the influence of filtering multiple signals in a signal section by section manner, the vertical ground reaction force (vGRF) was estimated from the computed vertical center of mass (COM) acceleration of lower limb segments throughout the stance phase after adding noise to the limb segment coordinates.

Body segment COM displacements and accelerations were estimated ten times using noiseless kinematic signals, and after the addition of noise (0.1 mm root mean square) using three signal processing techniques. 1) The “typical” technique in which all kinematic signals were filtered at a single filter cut-off frequency (the mean of the autocorrelation-based procedure [ABP; 3] cut-off frequencies for the body segment COM displacements), 2) a whole signal ABP technique which saw each body segment COM displacement signal filtered with a cut-off frequency specific to that segment, and 3) the segment filtering technique (ASFP) where the segment COM signals were broken into sections based on the variation in the Teager-Kaise Energy Operator (TKEO) of the estimated vGRF from the “typical” filtering method above [1,4]. In brief, this previously developed segment filtering technique applied the ABP to each section of the given signal to produce a whole signal displacement estimate corresponding to each signal section. These estimates were then joined together such that each section of the final signal contained the acceleration estimate derived from applying the ABP to that signal section.

Results and Discussion

The ASFP was better able to match the impact peak of the simulated vertical ground reaction force than both a typical approach and the ABP as demonstrated by a reduced absolute peak error (Table 1). This was accomplished by allowing for a filter with a higher cut-off frequency during the impact portion of stance. Additionally, the ASFP better attenuated oscillations in lower frequency portions of the signal (Figure 1).

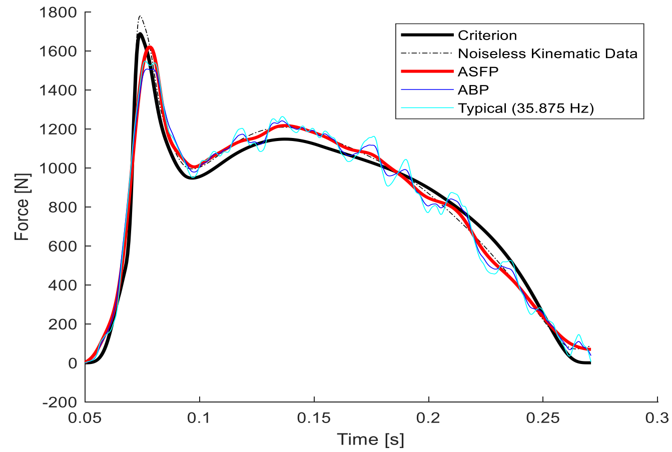

Figure 1: Vertical ground reaction force and estimates from noiseless kinematic signals and three filtering techniques.

Significance

When accurate magnitudes of kinetic and kinematic derivatives are of interest in impact-like biomechanical tasks, removing the appropriate amount of noise in measured signals is of great importance. Commonly, multiple signals are processed with a common Butterworth filter cut-off frequency, potentially inappropriately handling the variation in signal to noise ratio between body segments and signal sections therefore poorly estimating the magnitudes of interest. By implementing processing techniques which are sensitive to changing frequency content, such as the ASFP, more accurate estimation of common measures such as vGRF are attainable.

References

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Table 1: The percentage root mean square error (%RMSE) for estimating the vertical ground reaction force (vGRF) from kinematic signals and the error in estimating the vGRF impact peak value.

Method	%RMSE	Absolute Impact Peak Error [%]
Noiseless Kinematic Signals	6.0	5.4
ASFP	9.4 ± 1.1	5.1 ± 4.3
ABP	9.6 ± 0.8	11.3 ± 3.3
Typical Filtering	10.18 ± 0.9	8.6 ± 3.4