A Filtering Procedure to Process Non-Stationary Signals

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Summary

A procedure is presented by which a non-stationary signal can be partitioned into sections to apply different Butterworth filter cut-off frequencies to respective sections when necessary. The Teager-Kaiser Energy Operator (TKEO) is used to divide the signal into sections based on their energy. The procedure produces improved derivative estimates compared with commonly used signal processing approaches.

Introduction

The computation of accurate derivatives is often crucial in processing biomechanical data. A Butterworth filter is commonly used to reduce sampled signal noise prior to differentiation. The problem lies in selecting a filter cut-off frequency which retains the signal of interest whilst removing some of the noise. If the cut-off is too low important aspects of the signal can be removed, but if it is too high too much noise remains. Both instances produce poor derivative estimates.

A typical approach utilizes the same cut-off frequency for the whole sampled signal, but the frequency components of a signal can vary with time. To accommodate such a signal, a procedure is proposed which uses different cut-off frequencies for separate sections of the sampled signal. This approach is advantageous for preserving the frequency components from both motion and force data when performing inverse dynamics on tasks with an impact [1].

Methods

To determine sections of a signal with different frequency components, the TKEO of the signal was computed [2]. Three times the median absolute deviation of the TKEO served as criterion for outlier detection [3], where the outliers became a new section. Filter cut-offs were then determined for each section using the Autocorrelation Based Procedure [ABP; 4].

To evaluate this procedure, a data set with noisy displacement data and criterion acceleration data was used [5]. This data set contains a non-stationary signal. Two processing approaches were taken, 1) determine the cut-off frequency for the whole noisy data set, and 2) determine the separate cut-off frequencies for the individual sections of the data set. Following computation of derivatives, estimates were compared with the criterion acceleration values using the percent root mean square error (%RMSE).

Results and Discussion

A single ABP determined cut-off frequency applied to the whole data set produced a %RMSE of 41.4%, whereas with the data divided into three automatically determined sections the %RMSE was 27.2% (Table 1). As a point of comparison, a generalized cross-validated quintic spline (GCVQS) produced a %RMSE of 38.1% [4].

The criterion acceleration signal contains two periods of high acceleration magnitudes, giving distinct minimum and maximum acceleration values (Figure 1). Compared to commonly used procedures, estimates of these accelerations were comparable for the maximum and significantly better for the minimum (Table 1).

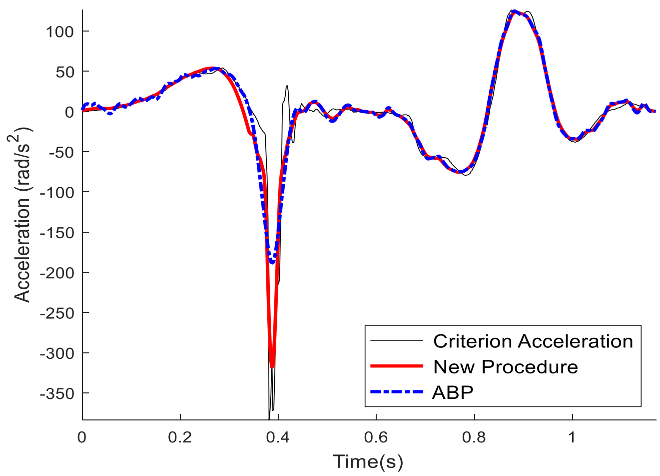

Figure 1: Criterion acceleration data and estimates.

Conclusions

A new procedure for the optimal filtering of a non-stationary signal has been presented, its evaluation using a common test data set demonstrates improved acceleration estimates compared with other commonly used procedures.

References

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Table 1: Percent Root Mean Square Error (%RMSE) for computing signal acceleration using the new procedure, the ABP, and the GCVQS.

Method	%RMSE	%Error for Signal Min.	%Error for Signal Max.
New Procedure	27.2	17.1	2.2
ABP	41.4	50.8	1.1
GCVQS	38.1	34.7	1.8