A UNIFYING APPROACH TO DETERMINE THE NUMBER OF PADDING POINTS WHEN DIGITALLY FILTERING KINEMATIC DATA

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INTRODUCTION

Signal sampling frequency and the low-pass digital filter cutoff frequency are factors that may influence the minimum number of padding points when applied to digital filtering of kinematic data that are often omitted from data processing descriptions. Amplitude distortion in response to a step input before converging on the true value of the input is a characteristic of the underdamped and recursive Butterworth filter (Robertson and Dowling, 2003). Due to this period of amplitude distortion, it is important to either collect data records of durations beyond the events of interest or add points to the beginning and end of data records to reduce amplitude distortion caused by the filtering process. The purpose of this investigation was to determine the influence that the ratio between filter cutoff frequency and signal sampling frequency (f_c/f_s) has on the minimum number of required padding points using 3 different extrapolation techniques.

METHODS

Two kinematic recordings, each 30 seconds in length, representing signals with high and low deterministic variation were obtained from a previous investigation (Beach et al., in press). Signals from the original investigation were sampled at a frequency of 64 Hz. Kinematic data were resampled at frequencies from 40-128 Hz at intervals of 1 Hz while the low-pass filter cutoff frequency was varied from 2-10 Hz at intervals of 0.5 Hz. This generated a set of 1513 combinations of filter cutoff and signal sampling frequency. Prior to filtering, a window of data was removed from the resampled kinematic signals between 4.65 and 10.93 seconds. This section of data served as the test signal. Padding points were incrementally added to the beginning of the test signal with three different techniques (first order polynomial, third order polynomial, and data reflection) until 2 seconds of padding points had been added to the test signal. The test signals were then dual-pass filtered using a 2nd order low-pass digital Butterworth filter.

Each resampled 30 seconds record was filtered using the identical digital filter as the corresponding test signal. The identical duration was removed from the resampled and filtered 30 seconds record and served as the criterion signal. Padding points were removed from the filtered test signal and the root mean square difference (RMSD) between the filtered test and criterion signals was calculated during the first second of data for each increment in the number of padding points. This produced an RMSD that was a function, R(p), of the number of padding points. The minimum number of padding points for a combination of sampling and cutoff frequency was defined as the number of padding points required to attain a constant RMSD or steady state defined by $R'(p) = R''(p) = 0$.

RESULTS

The RMSD between the filtered test and criterion signals exhibited an oscillatory pattern that achieved a steady state response. A non-linearly decreasing power-law relationship was observed between the minimum number of padding points and f_c/f_s (Table 1).

Method	α	β	R^2
1st order	2.538	-0.748	0.937
3rd order	1.706	-0.985	0.873
Reflection	2.584	-0.804	0.912

Table 1 – Curve fit coefficients relating the number of padding points (P) to the ratio between the cutoff frequency and the sample frequency (f_c/f_s) for the kinematic signal with larger deterministic variation. The general equation used for the power-law curve fit was $P\left(\frac{f_c}{f_s}\right) = \alpha\left(\frac{f_c}{f_s}\right)^{\beta}$.

Padding points that were added beyond the determined minimum did not change the RMSD. The signal with larger deterministic variation required more padding points than the signal with minimal variation.

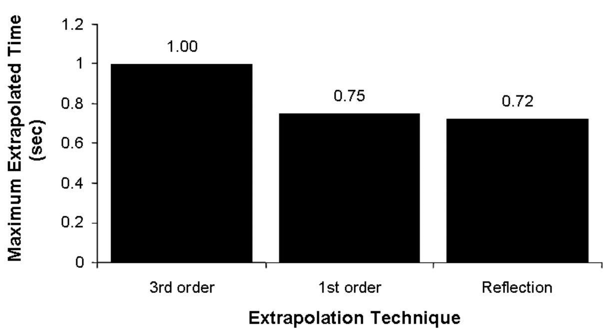

Figure 1 – Maximum extrapolated time for each of the three extrapolation techniques.

The largest extrapolated duration to produce a constant RMSD was 1 second (Figure 1).

DISCUSSION

As a general criterion, we suggest a minimum duration of one second of data be extrapolated for all kinematic recordings prior to digital filtering. This is based on the result that one second was the maximum extrapolated time, for all 1513 combinations of sampling and filter cutoff frequencies, across each of the three extrapolation techniques. A more suitable alternative to data extrapolation is to collect an extra second of superfluous data at the beginning and end of the desired sample period that can be removed following digital filtering. Adding excessive padding points beyond the determined minimum did not increase nor decrease the discrepancy between the filtered test and criterion signals which implies that overestimation of the minimum number of padding points is not detrimental to error determination.

SUMMARY

The current work extends previously published padding point criterions (Smith, 1989) by demonstrating that sampling and cutoff frequency will both affect the minimum number of padding points to be added prior to digital filtering. It is suggested that a minimum of 1 second of extraneous data be used when using a low pass recursive digital filter to remove noise from kinematic data.

REFERENCES

Beach, TAC et al. (in press). *Hum Mov Sci*.
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