A filtering procedure to process non-stationary signals

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Introduction

- Many studies in biomechanics rely on accurate derivative estimation.
- Appropriate filters can reduce the influence of noise on signal derivative estimation.
- A single filter cut-off frequency may be inappropriate for non-stationary signals (i.e., signals with time-varying frequency components).
- **A new procedure is presented which automatically segments signals based on their frequency profiles then filters segments separately.** The procedure is applied to a noisy angular displacement signal and results are compared with the reported reference angular acceleration signal [1].

Methods

- Time-varying signal energy estimated using Teager-Kaiser Energy Operator (TKEO; 2).
- Signal energy change points detected with 3 x Median Absolute Deviation (MAD) criterion [3].
- Detected *n* change points and corresponding time indexes within the signal $\{t_{cp_1}, \ldots, t_{cp_n}\}$.
- Defined *m* = *n* + 1 segments of the signal between change points $\{s_1, \ldots, s_m\}$.
- Autocorrelation-based procedure (ABP) automatically determined a cut-off frequency for each segment [4] $\{cof_{s_1}, \ldots, cof_{s_m}\}$.
- Each segment was filtered at its specific cut-off frequency then differentiated to estimate signal accelerations $\{\alpha_{cof_{s_1}}, \ldots, \alpha_{cof_{s_m}}\}$.
- Joined segments together
- $$\alpha_{final}(t) = \begin{cases} \alpha_{cof_{s_1}}(t), & t \le t_{cp_1} \\ \alpha_{cof_{s_2}}(t), & t_{cp_1} < t \le t_{cp_2} \\ \vdots & \\ \alpha_{cof_{s_m}}(t), & t_{cp_n} < t \le L \end{cases}$$

Where L is the final time index in the signal.

- Moving average used to smooth joins between adjacent segments.

Results

Table 1 – Percent root mean squared error between the reference angular acceleration and estimates. The single filter technique uses an autocorrelation-based procedure determined filter cut-off frequency for the full signal.

Procedure	Full Signal	Signal Minimum	Signal Maximum
Segment Filtering	26.6%	18.0%	0.8%
Single Filter	40.4%	49.6%	0.9%

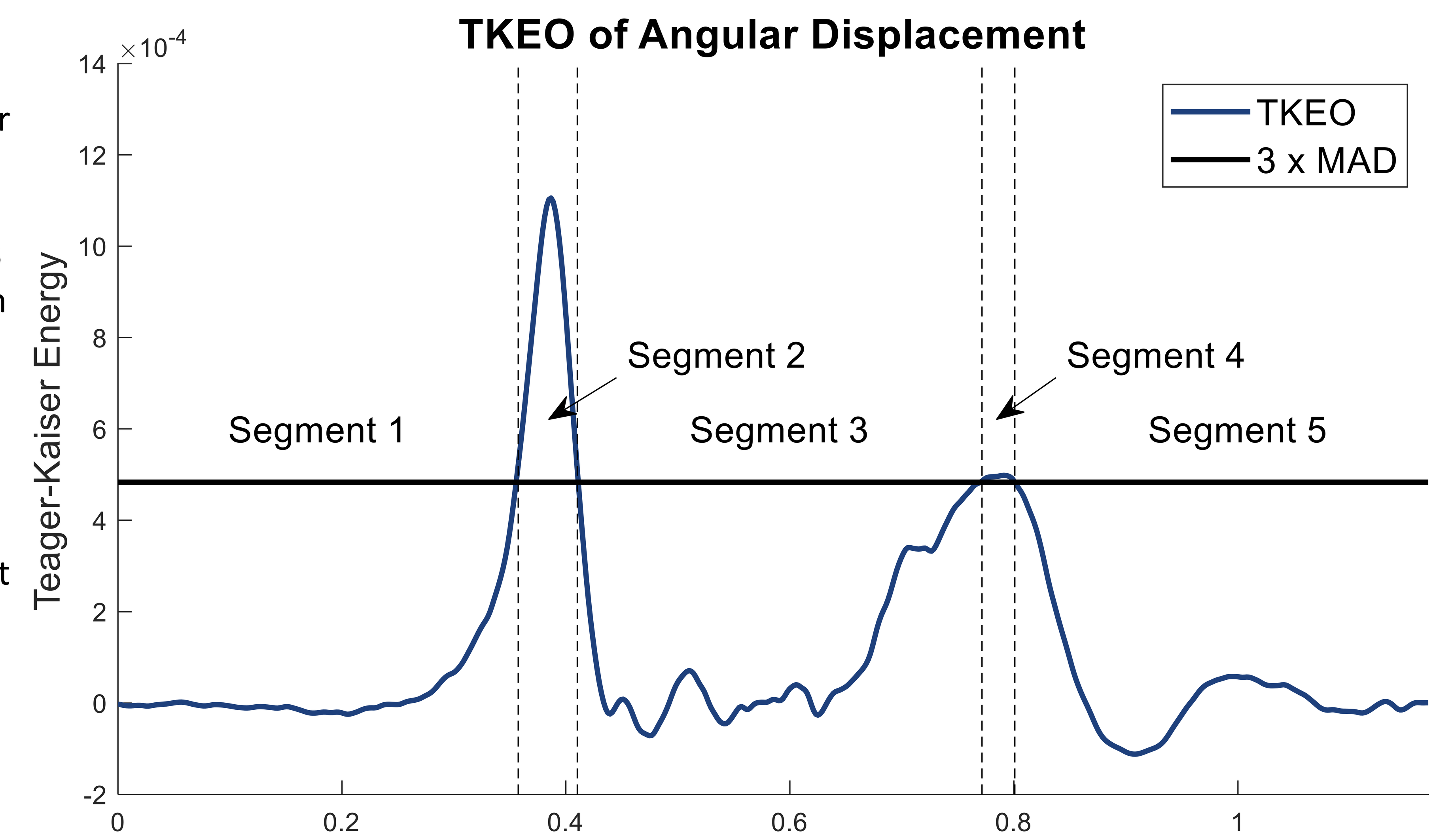

Figure 1- Teager-Kaiser Energy Operator (TKEO) and 3 x the Median Absolute Deviation (MAD) of filtered angular displacement signal. Vertical lines indicate change points.

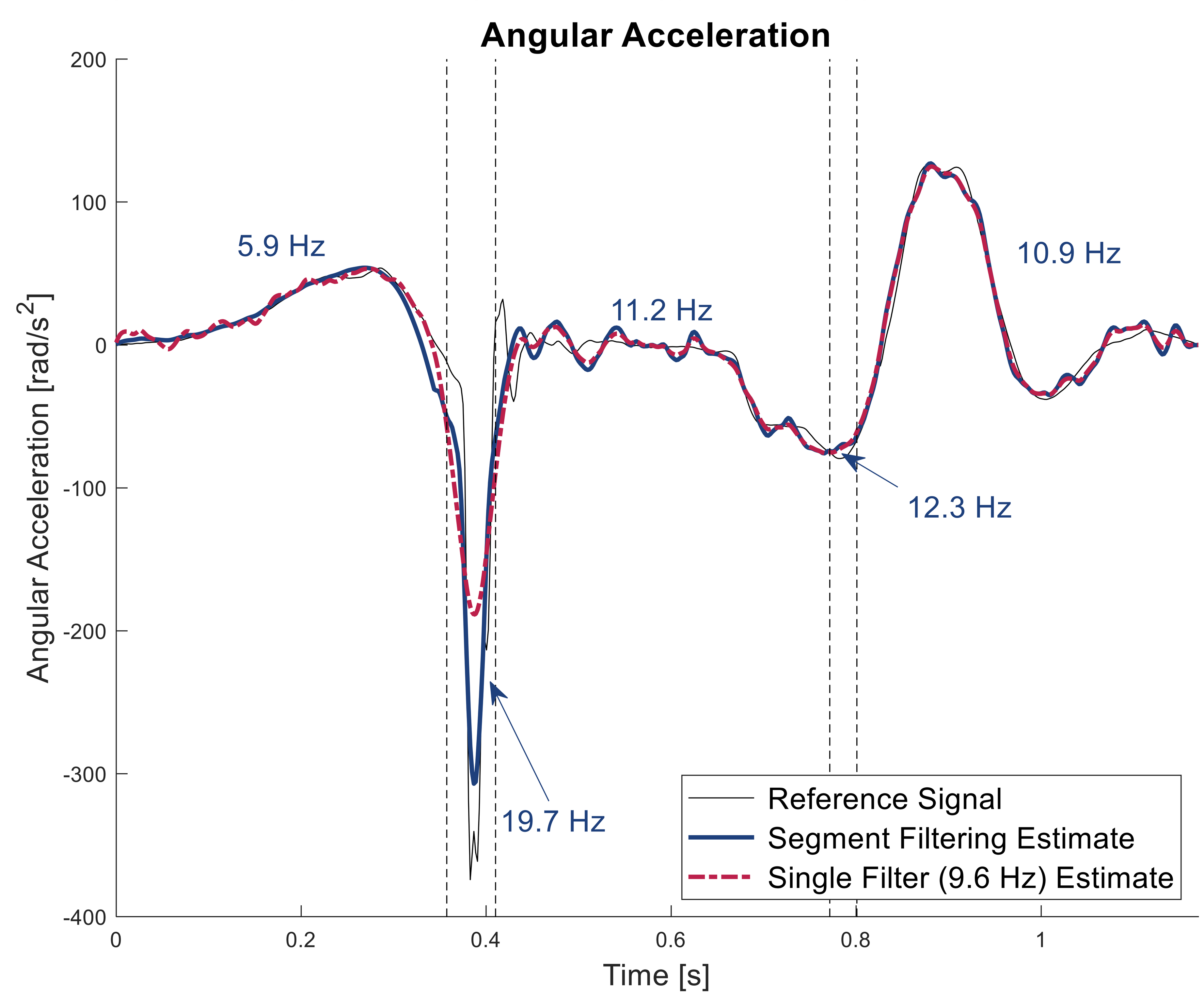

Figure 2 – Reference angular acceleration signal compared with estimates from segment filtering and single filter techniques. Frequency labels denote filter cut-off frequency used on that segment.

Conclusions

- **Segmenting signals and applying different filter cut-off frequencies to each segment resulted in better acceleration estimates of a noisy, non-stationary signal compared with a single filter cut-off frequency (the commonly used technique).**

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References
[1] Dowling JJ. (1985) *Biomechanics X-B;* Human Kinetics.
[2] Kaiser JF. (1990). *Proc. IEEE ICASSP-90,* 381 – 384.
[3] Leys et al. (2013). *J. Exp Social Psych,* **49.** 764-766.
[4] Challis JH. (1999). *J Appl Biomech,* **15**: 303-317.