ACCURACY OF THE CRITICALLY DAMPED AND BUTTERWORTH FILTERS USING THE ACCELERATION OF A FALLING OBJECT

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INTRODUCTION

The Butterworth filter has been the gold standard in filtering motion data since D.A. Winter introduced it in 1974. It was selected for its superior roll-off and its "flatness" in the passband. Unfortunately, it has the undesirable characteristic of being underdamped and therefore will overshoot the data during rapid transitions (Robertson & Dowling, 2003). An alternate filter that solves this problem–it is the critically damped filter (Robertson & Dowling, 2003). This filter has poorer roll-off than the Butterworth but by cascading the data through the filter a similar roll-off can be achieved. The purpose of this study is to compare the effectiveness of the critically damped and Butterworth filter using the known acceleration of a falling body–a golf ball.

METHODS

To validate the filters a golf ball was dropped and filmed while it bounced twice by a digital video camera in SP mode. The image was calibrated by a 1.0 x 2.0 m grid of control points. The plane was calibrated by a fractional linear transform that corrected for any camera misalignment. The motion data were captured and digitized using the APAS and then processed by the Biomech Motion Analysis System. The latter software allowed for filtering the data with 4th, 8th, 12th, 16th and 20th-order Butterworth or the critically damped filters.

RESULTS AND DISCUSSION

Figure 1 demonstrates that using 4th-order critically damped or Butterworth filters (CD-4 & BW-4) do not yield acceptably flat periods of constant acceleration during the flight phase of a ball. Although the average values of the acceleration (–10.00 & –10.05) were close to the correct value of –9.81 m/s^2 their standard deviations were quite high (0.69 & 0.48). Using 20th-order filters (CD-20 & BW-20) achieved better results by reducing the variability (0.23 & 0.34), but only the critically damped filter improved on predicting the correct acceleration (–9.96 vs. –10.11).

Figure 2 show the flight phase results when the data file includes the bounces that occur before and after the fight. In this case the 20th-order Butterworth caused significant distortion of the signal after and then before the two bounces. Some of these distortions were removed by clipping the fight phase so that the results did not exceed the boundaries of the graph. The Butterworth filter caused greater distortion as the order was increased whereas the critically damped filter caused less distortion at the ends of the flight phase.

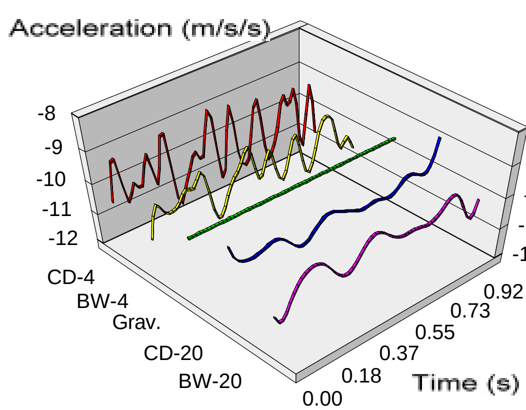

Figure 1. Accelerations of a ball in flight after various types of filtering

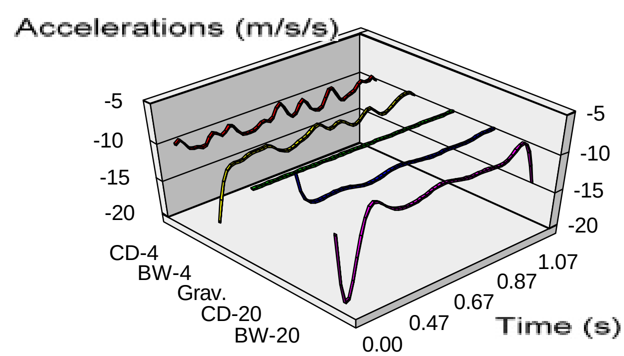

Figure 2. Ball acceleration during flight between bounces after various types of filtering

SUMMARY

The critically damped filter was shown to produce superior acceleration results as compared to the Butterworth filter when as suggested 20th-order was used to filter the motion of a body accelerated due to gravity. Higher order Butterworth filters caused significant distortion in the accelerations of the ball when rapid transitions precede or follow the flight phase. Caution should therefore be used with the Butterworth filter when higher order filtering is required.

REFERENCES

Pezzack, JC. *et al.* (1977) *J Biomech* 10:377-82.
Robertson DGE, Dowling, JJ (2003). *J Electromyogr Kines* 13: 569-73.
Winter, DA. *et al.* (1974) *J Biomech* **7:**157-9.