PIECEWISE LINEAR APPROXIMATION TO FILTER FORCE PLATE SIGNALS

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INTRODUCTION

Variability in biological movement has been traditionally treated as random fluctuation and heavily filtered in the frequency domain. However Newell and Slifkin [1] revealed that the "variance of the movement dynamics is as reviling as the invariance in terms of unpaking the nature of the system organization". Moreover the attempt to distinguish between deterministic and stochastic behavior of the postural sway has shown that the Center of Pressure (COP) time series is a typical nonstationary signal. This property of the signal limit the application of spectral techniques based on the Fourier transform [1].
We investigated the use of a Piecewise Linear Approximation (PWL) [2] to compensate for (a) the accuracy of the digital acquisition system and (b) for the threshold characteristic of the force plate in an attempt to preserve the stochastic characteristic of postural sway.

METHODS

Piecewise linear curves are often used to approximate complex boundary figures (sequence). Given a sequence f_n and a loss tolerance w, the PWL algorithm split the sequence into an upper ($f^+=f_n+w$) and lower ($f^-=f_n-w$) boundaries that define the error tunnel of the sequence f_n (figure 1).

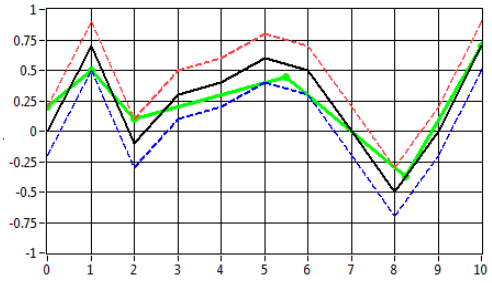

Figure 1: Piecewise Linear Approximation (green): original sequence (black), upper (red) and lower (blue) boundaries, .

Starting from one end of the tunnel the algorithm determines the longest single straight line within the boundary that approximate the sequence. The portion of the sequence approximated is deleted from the sequence itself and the algorithms starts again with the remaining portion of the sequence. This algorithm has been implemented in an OCCAM filter [4] to determine the strength of the noise in a deterministic signal. In compressing a noisy signal with a lossy compression algorithm, when the loss tolerance equals the strength of the noise the loss and the noise tend to cancel each other. The decompressed signal is the filtered signal [3]. OCCAM filter has been used in the present work to determine the strength of the noise (and consequently the tolerance w of the PWL approximation) produced by the digital acquisition system. To perform this analysis the force plate output was acquired with and without a 77kg weight (setup test). The result (figure 2) was found to be the same for both tests and all eight outputs of the force plate.

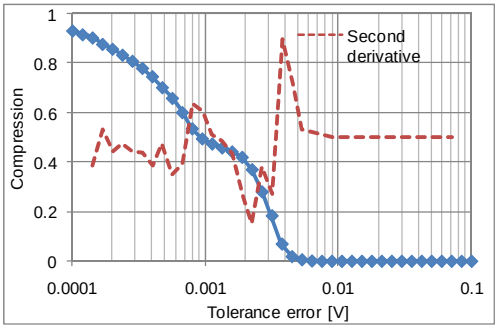

Figure 2: Compressed size versus allowed loss for the force plate output during the setup test. The peak of the second derivative (5mV) represents the loss that cancels the noise.

Postural sway of one of the author was acquired with a Kistler 9286AA force plate connected thought an external control unit (5233A2) to a NI PCI-6229 for digital acquisition. The eight outputs where filter at 500Hz, digitized at 3kHz (Raw Data). Three trials each of eyes open (EO) and eyes

closed (EC) were collected for 60s. The eight channel were postprocessed with a PWL algorithm with the loss tolerance derived during the setup test (5mV). The result was multiplied by the respective sensitivity of the force plate to determine forces. Then the PWL was applied again to take into consideration the threshold of the force plate (0.125N for X and Y output and 0.25N for the Zs output).

For comparison with previously used method the same eight channels were filtered using a 33 points median filter and a 201 points mean filter (15Hz). Calculation of the COP was performed according to the Kistler's formulas spreadsheet. COP-based measures of postural steadiness were perform according to Prieto [4].

RESULTS AND DISCUSSION

Table 1 reports the results of COP-based measures with Eyes Open (EO) and Eyes Closed (EC) for the two different postprocessing of the force plate data.

Figure 3 shows a comparison between original output from the force plate, the filtered signal at 15Hz and the approach proposed with a Linear Piecewise Approximation.

CONCLUSIONS

The PWL within the amplitude domain offered similar performance to the commonly used digital filtering methods (median and mean filtering) with regard to commonly used parameter for describing postural sway.

However, better tuning of this technique with a recursive OCCAM filtering algorithm may reveal stochastic behavior of the COP trajectory and provide different information about motor behavior of the postural control system.

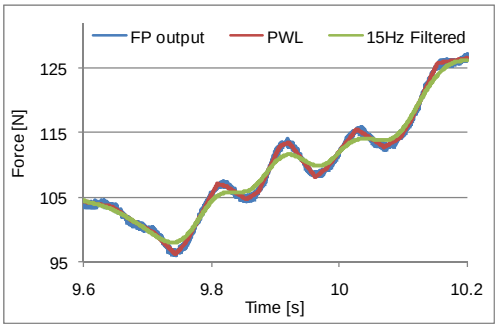

Figure 3: Original force plate signal (blue) filtered with a 15Hz mean filter (green) and approximated with a Piecewise Linear Algorithm (red).

REFERENCES

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2. Imai H. and Iri M. Journal of Information Processing 9(3), 159-162, 1986.
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4. Prieto T.E. et Al. IEE Transaction On Biomedical Engineering, 43(9), 956-966, 1996.

Table 1: COP-based measures with Eyes Open (EO) and Eyes Closed (EC) for the two postprocessing techniques of quite standing force plate data along with results reported by Prieto (1996).

Measure	**15Hz Mean Filter**		**Piecewise**		***Prieto(1996)***	
	EO	**EC**	**EO**	**EC**	***EO(YA)***	***EC(YA)***
mean distance (mm)	3.07±0.92	3.04±0.40	3.06±0.92	3.04±0.40	*3.12±1.11*	*3.85±1.65*
mean distance ML (mm)	1.52±0.18	1.95±0.30	1.52±0.18	1.94±0.30	*1.5±0.77*	*1.66±0.95*
mean distance AP (mm)	2.39±1.01	1.93±0.22	2.38±1.02	1.93±0.22	*2.42±0.97*	*3.10±1.29*
rms distance (mm)	3.55±1.08	3.44±0.51	3.55±1.08	3.44±0.51	*3.56±1.20*	*4.39±1.81*
rms distance ML (mm)	1.96±0.21	2.45±0.45	1.95±0.21	2.45±0.45	*1.85±0.91*	*2.06±1.17*
rms distance AP (mm)	2.93±1.18	2.41±0.27	2.93±1.18	2.41±0.27	*2.95±1.08*	*3.82±1.54*
range (mm)	8.73±3.47	8.81±1.58	8.73±3.39	8.87±1.62	*14.3±4.34*	*18.0±7.14*
range ML (mm)	11.21±2.43	13.59±1.88	11.30±2.44	13.61±1.84	*8.48±3.89*	*9.79±5.42*
range AP (mm)	13.91±4.68	13.18±1.65	13.91±4.59	13.15±1.63	*13.3±4.27*	*17.7±6.97*
mean velocity (mm/s)	5.31±0.38	6.00±0.54	5.30±0.40	6.05±0.59	*6.90±1.79*	*8.89±2.86*
mean velocity ML (mm/s)	3.03±0.27	3.39±0.36	3.01±0.25	3.47±0.37	*3.82±1.19*	*4.43±1.65*
mean velocity AP (mm)	3.76±0.27	4.24±0.36	3.77±0.34	4.25±0.41	*4.92±1.34*	*6.72±2.18*
95% conf ellipse area (mm^2)	107±49	111±32	107±49	111±32	*99±66*	*162±140*