`ModulateFlow`
Modulating diastolic flow or velocity waveforms

Jorge Mariscal-Harana

Department of Biomedical Engineering, King's College London, UK

Abstract.

This report presents `ModulateFlow`, a script for modulating diastolic flow or velocity waveforms.

1. Summary

Clinical blood flow or velocity waveform pre-processing can be difficult due to a low sampling rate (SR) and/or noise. This report describes how `ModulateFlow` deals with these two common problems by (a) using a cubic spline interpolation for low SRs; and (b) modulating the flow or velocity waveform during diastole to eliminate noise after valve closure.

2. Methods

`ModulateFlow` consists of three stages: (i) waveform interpolation; (ii) noise thresholding; and (iii) downslope projection. The methods used at each stage are now described in turn.

2.1. Waveform interpolation

If the number of waveform datapoints is smaller than 100, a cubic spline interpolation (`spline`) is applied to increase the number of datapoints to 100.

2.2. Noise thresholding

`ModulateFlow` identifies the maximum flow or velocity datapoint and excludes analyses the waveform from there.

Firstly, the following points are identified on the second derivative (SDPW):

- $\boldsymbol{a}$: The point of maximum value on the SDPW prior to the last local minimum on the SDPW.

2.3. Downslope projection

3. Using `ModulateFlow`

`ModulateFlow` can be used to calculate CV indices from either a pulsatile signal containing several pulses, or a single pulse wave. The input data, S, should be prepared as a structure with two fields: $S.v$, a vector of signal amplitudes, and $S.fs$, the sampling frequency of the signal. At its simplest, can be called using

```
cv_inds = PulseAnalyse(S);
```

where `cv_inds` is a structure containing individual fields for each of the calculated CV indices (named according to the abbreviations listed in Table **??**). Each index's field is itself a structure, containing the calculated value (*e.g.* `cv_inds.SI.v`, which is a median in the case of multiple pulses), and raw values for each pulse (`cv_inds.SI.raw`) if the input signal contains multiple pulses.

Additional functionality can be exploited by specifying additional inputs. Firstly, if the subject's height is provided in $S.ht$ then those CV indices which require height will be calculated. Secondly, options can be specified as a second input using

```
cv_inds = PulseAnalyse(S, options);
```

where `options` is a structure containing the following logical fields:

- `exclude_low_quality_data`: whether or not to exclude pulses with a low signal quality in the calculation of a median value for each CV index (only applicable when using an input signal with multiple pulses).
- `do_plot`: whether or not to plot an example pulse with fiducial points annotated (similar to those in Figure **??**).

Additional outputs can also be obtained using

```
[cv_inds, fid_pts, pulses, S_filt] = PulseAnalyse(S);
```

where `fid_pts` is a structure containing the indices of each fiducial point; `pulses` is a structure containing the indices of the onsets and peaks of each pulse, and the signal quality of each pulse (a logical where 1 indicates high signal quality); and `S_filt` is the filtered pulsatile signal to which these indices correspond.

4. Further Work

Ideas for improvement.

References

[1] M. Elgendi, "On the analysis of fingertip photoplethysmogram signals," *Current Cardiology Reviews*, vol. 8, no. 1, pp. 14–25, 2012.

[2] M. O'Rourke and D. Gallagher, "Pulse wave analysis," *Journal of Hypertension*, vol. 14, no. suppl 5, pp. S147–57, 1996.

[3] P. J. Chowienczyk *et al.*, "Photoplethysmographic assessment of pulse wave reflection: Blunted response to endothelium-dependent beta2-adrenergic vasodilation in type II diabetes mellitus," *Journal of the American College of Cardiology*, vol. 34, no. 7, pp. 2007–2014, 1999.

[4] S. C. Millasseau *et al.*, "Determination of age-related increases in large artery stiffness by digital pulse contour analysis." *Clinical science (London, England : 1979)*, vol. 103, no. 4, pp. 371–7, oct 2002.

[5] S. Alty *et al.*, "Cardiovascular disease prediction using support vector machines," in *2003 46th Midwest Symposium on Circuits and Systems*, vol. 1. IEEE, 2003, pp. 376–379.

[6] H. T. Wu *et al.*, "Novel application of parameters in waveform contour analysis for assessing arterial stiffness in aged and atherosclerotic subjects," *Atherosclerosis*, vol. 213, no. 1, pp. 173–177, 2010.

[7] J. M. Ahn, "New Aging Index Using Signal Features of Both Photoplethysmograms and Acceleration Plethysmograms." *Healthcare Informatics Research*, vol. 23, no. 1, pp. 53–59, jan 2017.

[8] M. Peltokangas *et al.*, "Parameters extracted from arterial pulse waves as markers of atherosclerotic changes: performance and repeatability," *IEEE Journal of Biomedical and Health Informatics*, vol. 2194, no. c, pp. 1–1, 2017.

[9] K. Takazawa *et al.*, "Assessment of vasoactive agents and vascular aging by the second derivative of photoplethysmogram waveform." *Hypertension*, vol. 32, no. 2, pp. 365–370, 1998.

[10] J. B. Hyun *et al.*, "Second derivative of photoplethysmography for estimating vascular aging," *Proceedings of the IEEE/EMBS Region 8 International Conference on Information Technology Applications in Biomedicine, ITAB*, vol. 00, pp. 70–72, 2008.

[11] T. Ushiroyama *et al.*, "Assessment of chilly sensation in Japanese women with lasor Doppler fluxmetry and acceleration plethysmogram with respect to peripheral circulation," *Bull. Osaka Med. Coll.*, vol. 51, pp. 76–84, 2005.

[12] C. C. Wei, "Developing an effective arterial stiffness monitoring system using the spring constant method and photoplethysmography," *IEEE Transactions on Biomedical Engineering*, vol. 60, no. 1, pp. 151–154, 2013.

[13] W. Karlen, J. M. Ansermino, and G. Dumont, "Adaptive pulse segmentation and artifact detection in photoplethysmography for mobile applications," in *Conf Proc Eng Med Biol Soc.* IEEE, 2012, pp. 3131–4.

[14] C. Orphanidou *et al.*, "Signal-quality indices for the electrocardiogram and photoplethysmogram: derivation and applications to wireless monitoring," *IEEE Journal of Biomedical and Health Informatics*, vol. 19, no. 3, pp. 832–8, 2015.

[15] N. Angarita-jaimes *et al.*, "Classification of Aortic Stiffness From Eigendecomposition of the Digital Volume Pulse Waveform," *Acoustics, Speech and Signal Processing, 2006. ICASSP 2006 Proceedings. 2006 IEEE International Conference on*, pp. 1168–1171, 2006.

[16] U. Rubins, "Finger and ear photoplethysmogram waveform analysis by fitting with Gaussians," *Medical and Biological Engineering and Computing*, vol. 46, no. 12, pp. 1271–1276, 2008.

[17] M. Huotari *et al.*, "Photoplethysmography and its detailed pulse waveform analysis for arterial stiffness," *Rakenteiden Mekaniikka (Journal of Structural Mechanics)*, vol. 44, no. 4, pp. 345–362, 2011.

[18] Y. Sawada, G. Tanaka, and K. ichi Yamakoshi, "Normalized pulse volume (NPV) derived photoplethysmographically as a more valid measure of the finger vascular tone," *International Journal of Psychophysiology*, vol. 41, no. 1, pp. 1–10, 2001.

[19] G. Tanaka *et al.*, "A novel photoplethysmography technique to derive normalized arterial stiffness

as a blood pressure independent measure in the finger vascular bed," *Physiological Measurement*, vol. 32, pp. 1869–1883, 2011.

[20] W. C. Tsai *et al.*, "Association of risk factors with increased pulse wave velocity detected by a novel method using dual-channel photoplethysmography," *American Journal of Hypertension*, vol. 18, no. 8, pp. 1118–1122, 2005.

[21] M. Peltokangas *et al.*, "Combining finger and toe photoplethysmograms for the detection of atherosclerosis," *Physiological Measurement*, vol. 38, no. 2, pp. 139–154, 2017.

[22] J. Allen *et al.*, "A prospective comparison of bilateral photoplethysmography versus the ankle-brachial pressure index for detecting and quantifying lower limb peripheral arterial disease," *Journal of Vascular Surgery*, vol. 47, no. 4, pp. 794–802, 2008.

[23] J. Allen *et al.*, "Photoplethysmography detection of lower limb peripheral arterial occlusive disease: a comparison of pulse timing, amplitude and shape characteristics." *Physiological measurement*, vol. 26, no. 5, pp. 811–21, 2005.

[24] E. Zahedi *et al.*, "Analysis of the effect of ageing on rising edge characteristics of the photoplethysmogram using a modified windkessel model," *Cardiovascular Engineering*, vol. 7, no. 4, pp. 172–181, 2007.