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On the use of the wavelet transform for trabecula-scale sarcomere feature detection

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Background

To assess the contribution of inhomogeneous contraction to mechanical performance in cardiac trabeculae, we want to simultaneously determine the location of a population of sarcomeres within an image, as well as quantify the average sarcomere length of that population. To this end, we investigate the wavelet transform as a well established approach to temporal-frequency localisation problems.

The wavelet transform is akin to the Fourier transform in that it is a useful technique for examining the frequency content of a signal. In contrast to the Fourier transform, the wavelet transform is also capable of temporally (or spatially) resolving the frequencies of interest by trading off frequency resolution for temporal.

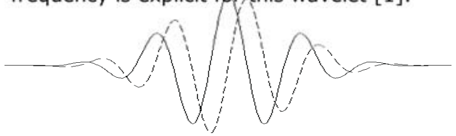
The wavelet transform is computed in a similar fashion to a Fourier transform. The inner product between a signal and a transform kernel is computed. The standard Fourier kernel:

$$e^{-i\omega t} = \cos\omega t - i\sin\omega t$$

is replaced with a family of user selected wavelet kernels which are generated by applying a scale and shift parameter (*a* and *b* respectively) to a mother wavelet function.

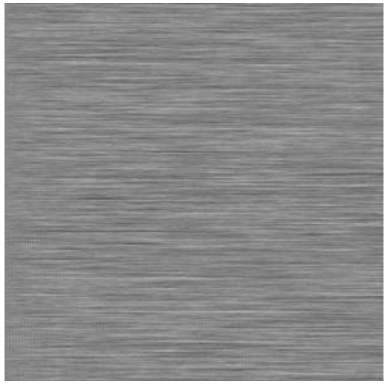
$$\varphi_{a,b} = \frac{1}{\sqrt{|a|}}\varphi\left(\frac{t-b}{a}\right)$$

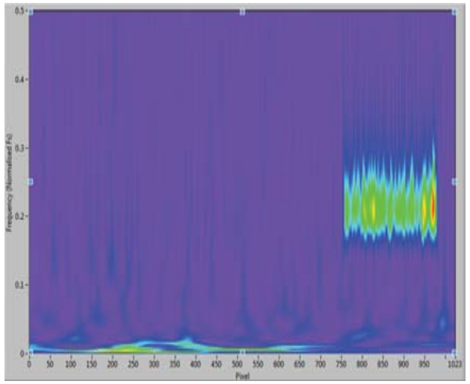
The scale parameter can be thought of as the inverse of frequency. The choice of wavelet function is application and user dependent. In our case, we have used the complex Morlet wavelet shown below, as the relationship between scale and frequency is explicit for this wavelet [1].



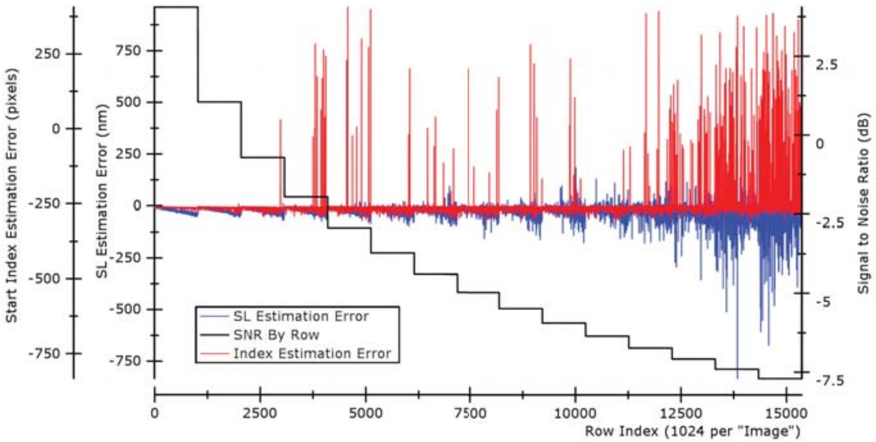
Method

Test images were generated by distributing sinusoids of known, decreasing frequencies down the rows of a 2D matrix representing the image. Each sinusoid was of random length and started at a random location in the row. Each row was then corrupted with a noise model designed to mimic the typical 1/f noise observed in images of cardiac trabeculae. The noise power was increased for each successive synthetic image to determine the noise floor bounding the detection of sarcomere-like signals. An example image at relatively high SNR (0.1 dB) is shown below on the left.





The Analytic Wavelet Transform [2] was performed in a row-by-row fashion for each image, and the wavelet coefficients which resided in the frequency range of interest, and exceeded a user defined threshold, were averaged to give an estimate of sarcomere length within the region of interest. The onset of the “high contrast” region, as detected by the algorithm, was also recorded and compared against the true onset. An example output of the AWT for a single row is shown above on the right.



Results

The results of AWT processing are shown in the centrepiece graph. We observe that as the SNR (plotted in black) drops over each successive image, the estimates of both sarcomere length and location become more unreliable. If we define acceptable error as approx. 5% of sarcomere length, we observe that a signal to noise ratios greater than -5dB will result in “good” estimates. Note also that the error in the estimate depends on the underlying frequency of the signal. The resolution is higher at higher frequencies, hence we see an increase in error down the rows of each image as the sinusoid frequency decreases.

Discussion

The reliability of the estimate is strongly dependent on the wavelet coefficient threshold chosen by the user. The appropriate threshold is, in turn, dependent on the contrast in the signal of interest, or equivalently, the signal to noise ratio. The next step is to determine if there are grounds for computing an appropriate threshold from an initial “calibration” image at the start of experiments.

References

[1] Debenath, L, (2002). “Wavelet Transforms & Their Applications”, Springer Science+Business Media New York

[2] Selesnick, I. W, Baraniuk, R. G, Kingsbury, N. G, (2005). “The Dual-Tree Complex Wavelet Transform.” IEEE Signal Processing Magazine.