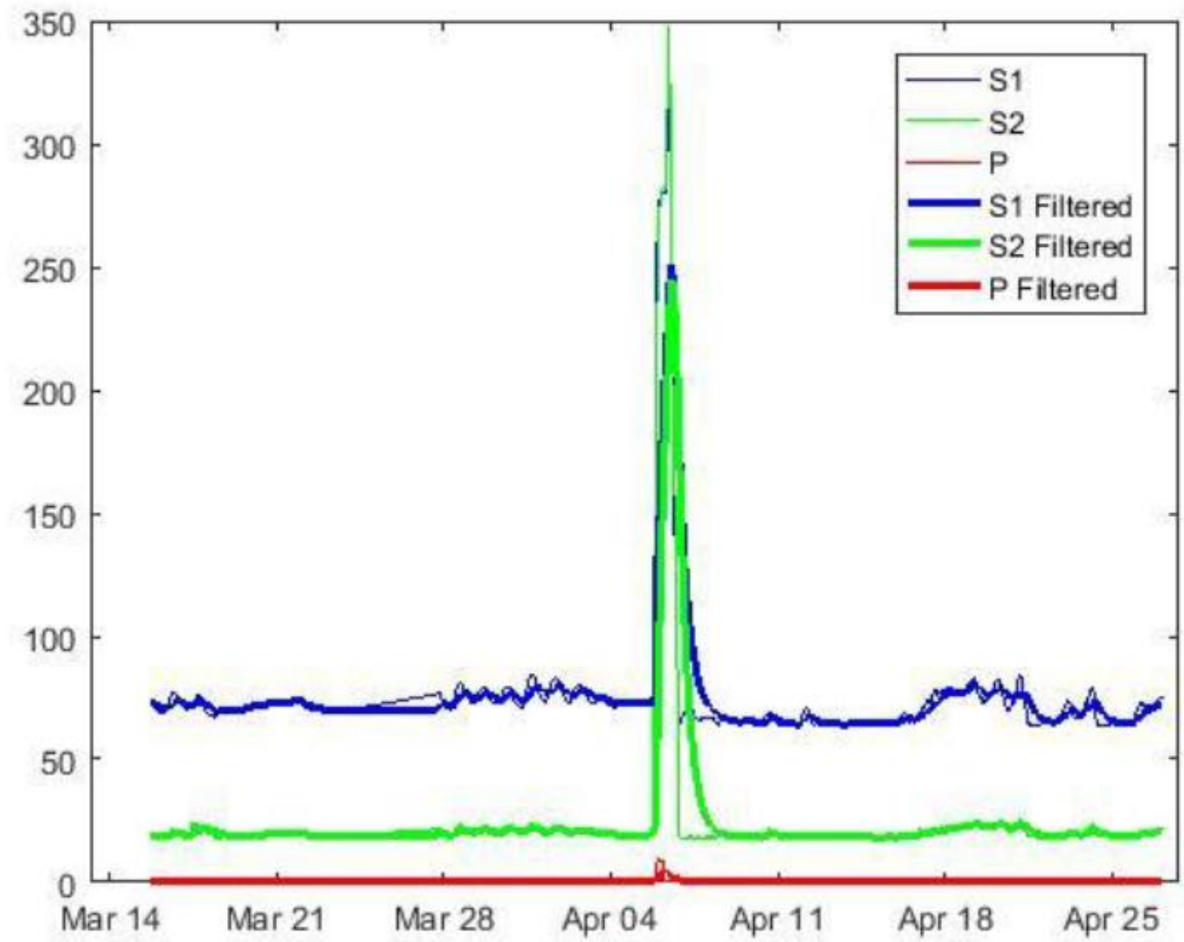
LNA Dewar Monitoring Project Progress 3

In the previous report, the results from Kalman filter and extraction of possible features from the spectrogram of the input time domain signal was discussed. It was also discussed that the spectrogram provided less discrimination between the time before the event and after the event. As advised, some further transforms were taken into study that are also being used in seismic wave studies.

For the comparison STFT , Wigner-Ville, Teager Energy Operator and Hilbert Huang Transform were considered. All of these techniques were applied on the following test data:



Preprocessing

It is expected that in the actual scenario, the sensor readings for the Dewar sensors will be logged in real time and out of that logged data, a certain window can be extracted upon which processing should take place to come to a decision about the Dewar's current state.

For the test runs, this window size in terms of the no. of samples of sensor data that will be used for decision making is defined to be 5000. So before every new sample, 5000 previous samples will be extracted from the history and processing will be done on these samples. Selecting an optimal window size is a trade-off between the required computational time for processing and the information that the extracted signal will contain. Shorter window sizes will imply that the extracted signal will not contain long-term variations in the sensor data while very long window sizes will increase computational time.

The extracted window is first downsampled by a factor of 100 and then Kalman filter is applied for signal smoothing. So eventually, the transform algorithm will work on a signal vector of size 500 that will represent 5000 samples of the original signal in time domain.

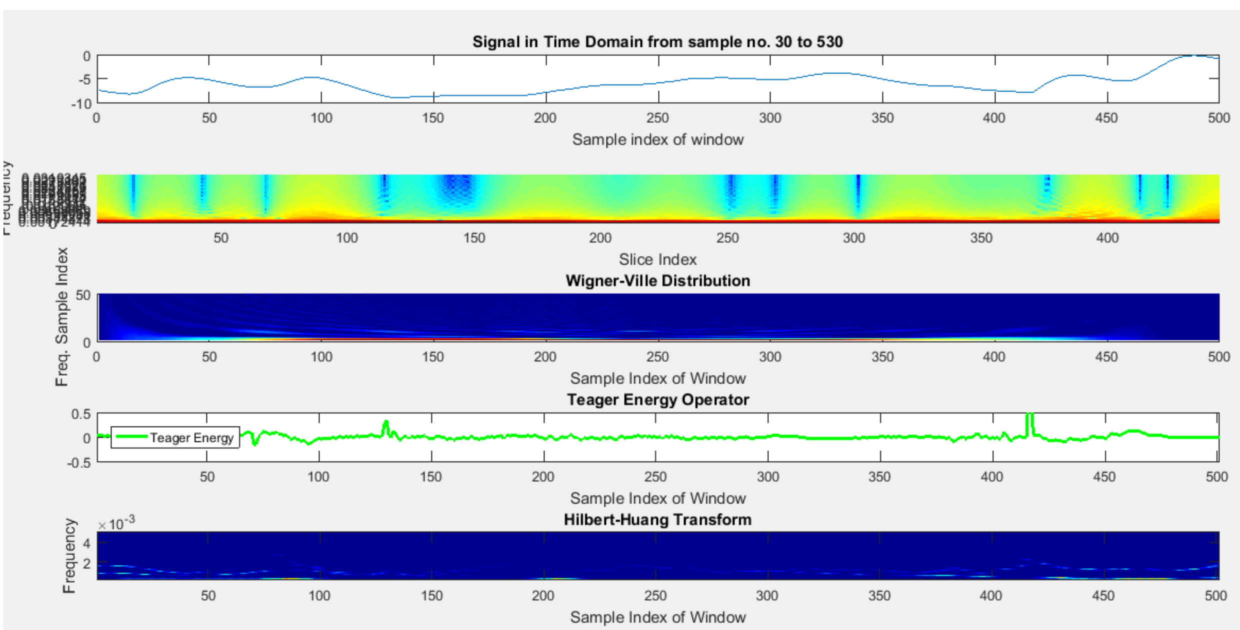
Comparison between transforms

While reviewing literature on earthquake studies, I learnt that a comparison between the performances of different transforms is done on the basis of the frequency and time resolution that a given transform can achieve for the data under study. So it means that a transform can be said to be better if it can differentiate the existing frequencies much better than others.

I applied STFT, Wigner-Ville, Teager Energy Operator and Hilber Huang Transform simultaneously on the test data.

The test data had 219400 samples in total. After downsampling by 100, this becomes 2194. Kalman filter was applied on this downsampled signal. A sliding window of size 500 was moved over this downsampled signal with a step size of 10 samples. On this extracted window, the transforms were applied.

The result of one of the iteration is as shown below:



However to get a better idea of the results, I made a video of all the iterations and uploaded on drive. You can see the results for comparison for this test data here:

https://drive.google.com/open?id=1t-iPJvexkH4olpVcTTVChqkDCycRZuQ_

The prominent result from the comparison that I understand is that Hilbert Huang Transform provides the best spectral resolution amongst all the time-frequency series. This may not readily be visible in the video but you'll be able to see one bright line near the x axis and another disjointed line a little above that appears strongly at some times and disappears at others.

The STFT gives a strong result for higher frequencies also but due to spectral leakages, it is very hard to different between frequencies.

The Teager Energy operator does not provide time-frequency image but instead provides a measure of the system's energy as defined by the maths of this operator. Having said that, I am unable to see any noticeable difference using this for time before and after the event.

The Wigner Ville provides better frequency resolution than STFT but not as well as HHT.

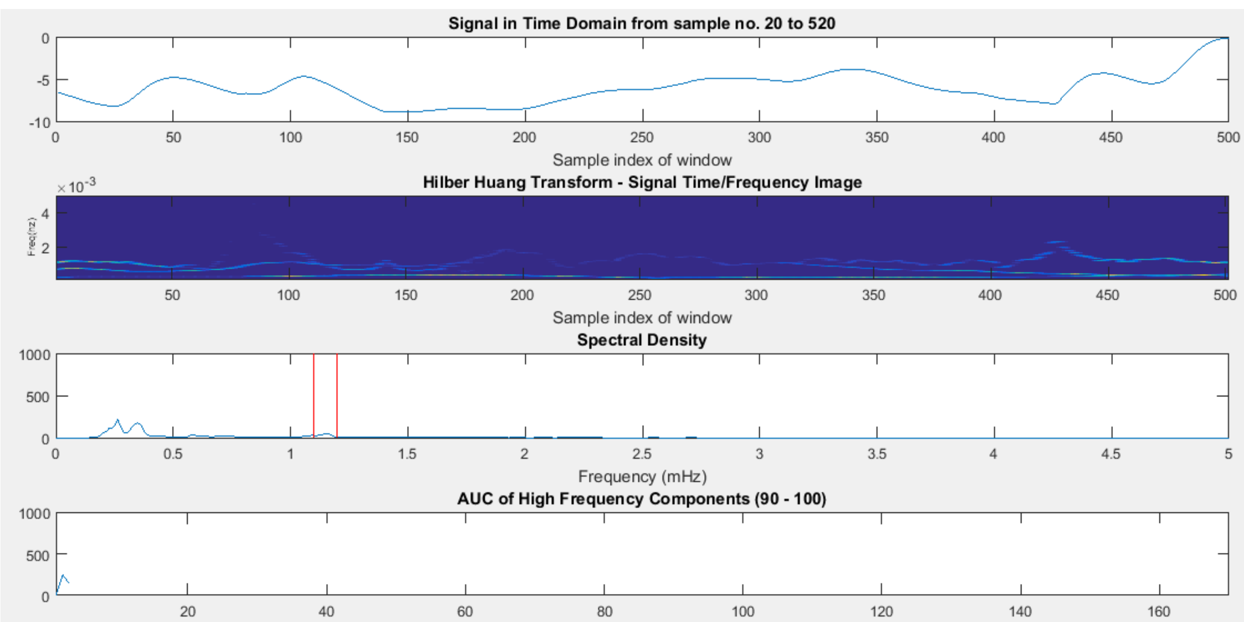
I do think that these observations are consistent with the theory of these transform. Especially for HHT, I have read about its usefulness for representing non-linear / non-stationary signals and it use in earthquake studies.

HHT Analysis

Noting that HHT performs better, it was interesting to extract possible features from it. The result of the HHT is a time-frequency image. To get a measure of the dominant frequencies at a given time, the spectral density of the frequencies was calculated. This is simply an integral over each frequency for the complete window.

This was done to analyze which frequencies become more apparent at different times of the original signal.

Following is the result for one of the iteration:



Here the first plot is the downsampled signal in time domain. The second plot is the HHT time-frequency image. The third plot is the Spectral Density. The fourth plot is the area under the curve (AUC) for the region defined between the two vertical red colored lines.

Again, to get a better impression, please see the following video:

https://drive.google.com/open?id=1klMvrVXjF1P7uiFgcrvUWuRlTVKN_0LF

From the spectral density plot, we can see that a band of lower frequencies always exist in the signal but as the maintenance event is approach, some higher frequencies become apparent and the AUC thus increases. The AUC is initially very low and as the event is approached it increases. When the event is visible in the time domain window, the AUC goes very large but when the event passes, the AUC drops to a low value.

I have extracted in total 7 data sets which include a maintenance event. Amongst all, this data set is the one in which the AUC follows this trend in the most optimal manner. Besides this, at least two more data sets follow this trend. One of the data set is too noisy so the Kalman filter gains that have been set do not filter it sufficiently and so I exclude that data set. One of the data set does not follow this trend. Other than this, the other two have maintenance events very nearby so I am not very sure of the results for them.

Key-points

From the test runs that I did, I feel that HHT is much better than other transforms.

The HHT can be used for feature extraction by selecting appropriate AUC regions in the Spectral Density curves for both the temperatures and pressure. For this I also worked on the 3D scatterplots further but as the results still remain incomplete for that, I am unable to share them

Please review the results and provide your valuable suggestions and feedback. Thanks!