HUMS2023 Data Challenge Result Submission

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Institutions: MathWorks Australia

Publishable: Yes

1. Summary of Findings

Table 1 Summary of Analysis Results

#	Detection & Trending	Data file name/number	Comments
1	Consistent detection on at least one signal channel; i.e. the fault indicators remain consistently above the threshold.	194	
2	Confirmed detection on at least two signal channels; i.e. the fault indicators remain consistently above the threshold.	194	
3	Clear multi-channel indication of the characteristic fault features; i.e. faulty planet gear meshing with both the ring and sun gears.	194	
4	Confirmed trend of fault progression; i.e. a consistent increasing trend started from which file number/name.	Not Attempted	
5	Confirmed trend of accelerated fault progression; i.e. a consistent exponential increasing trend started from which file number/name	521	

2. Analysis Methods

As this is an unlabelled data challenge we focused on the following specific points:

1. Detection of crack initiation
2. Detection of crack completion

We followed an unsupervised data driven approach, specifically:

1. The hunting tooth average data was transformed to extract the SSA Carrier and Planet signals so that all three could be analysed
2. All three signals were windowed with no overlap so that we could better discriminate phase angle effects
3. Regular statistical properties, such as mean, max, and spectral kurtosis estimates were computed for each window, resulting in over 900 individual channels

4. The individual channels were smoothed and ranked for their uniformity in predictive power using a monotonicity estimator
5. A principal component analysis was used to fuse the important features, those with the most monotonicity, into three principal components.
6. Finally, following a visual inspection of the scatter of the PCA plot semi-supervised clustering was used to split the records into a pre-crack and crack formation to 95% confidence level. Also, the PCA scatter showed the final acceleration phase. We interpreted these clusters as pre-crack and crack growth phases

At the time of submission, we did not have a reliable signal for the trend indicators.

3. Illustrating Figures

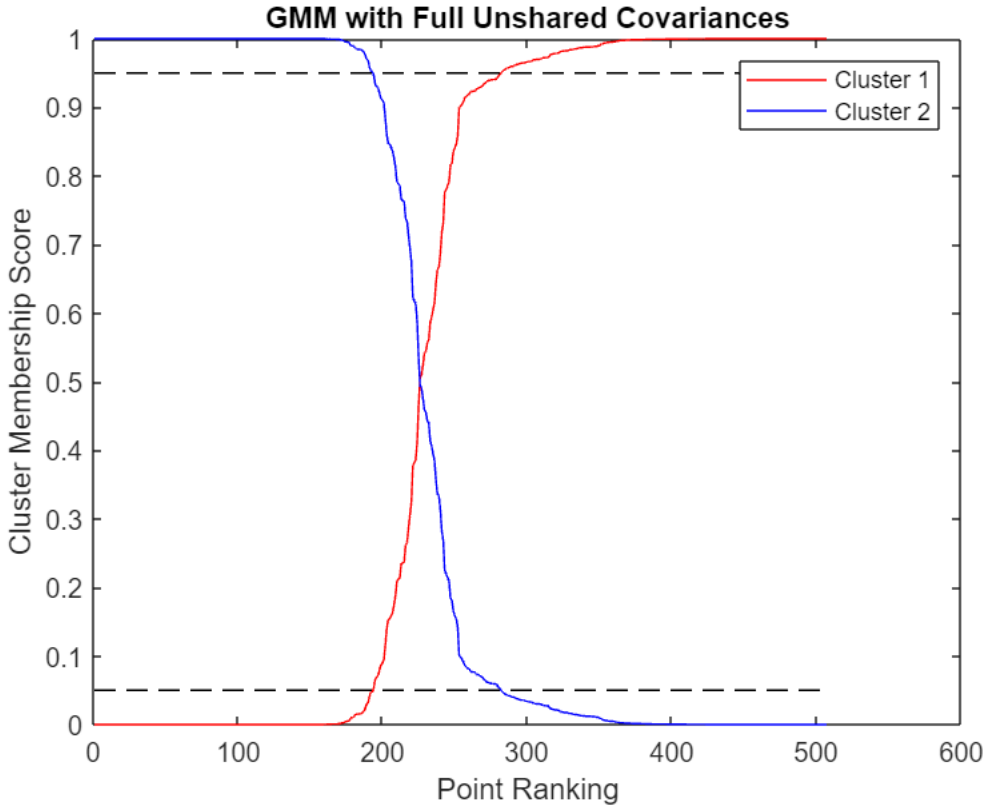

Figure 1 – cluster significance plot showing the cross over of the 95% confidence level at point 194 between the stationary crack period and crack growth phases.

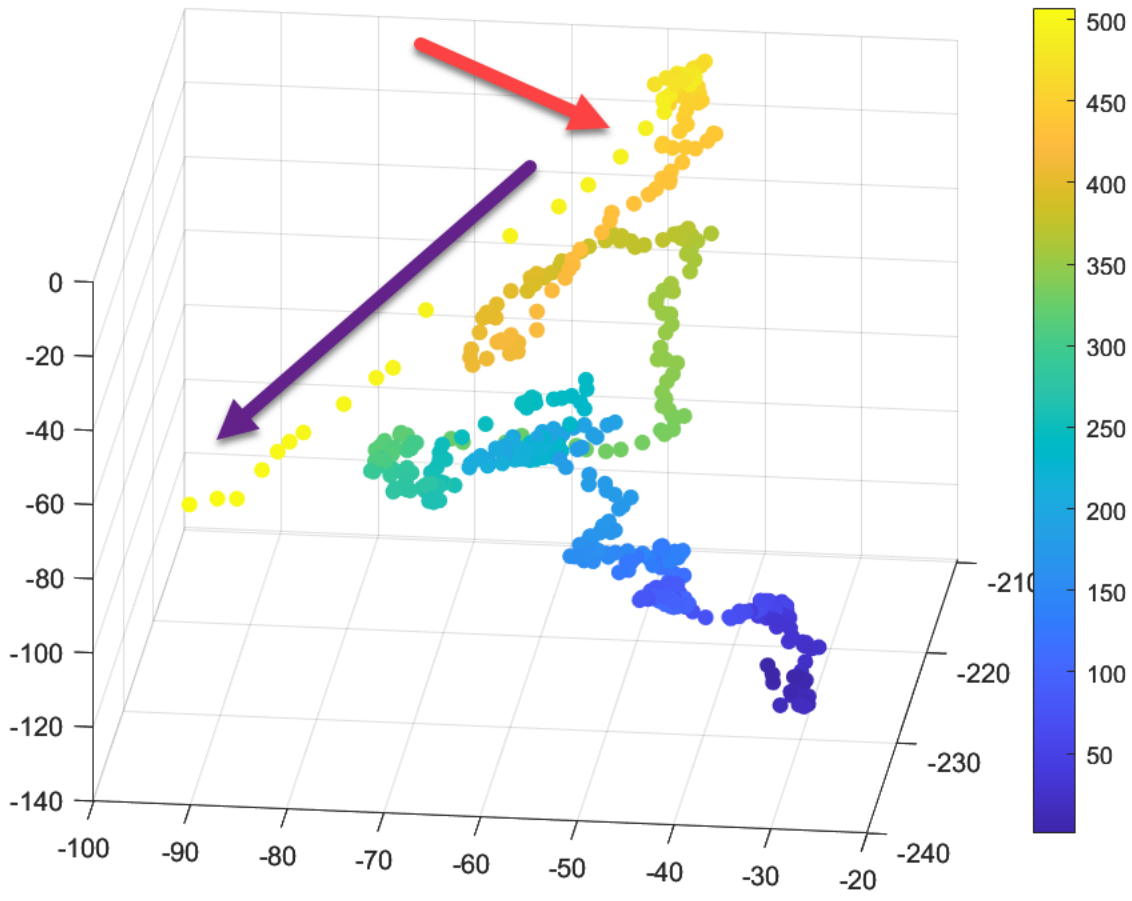

Figure 2 – scatter of the first three principal components, with the final acceleration start highlighted in red arrow, with the acceleration and deviation from the second cluster highlighted with the purple arrow

4. Characteristic Fault Signatures of Early Detection

See below

5. Fault Progression Trending Curve

Not attempted

6. Description of Analysis Methods

Description of fault detection method

Not being gearbox specialists, we began with a simple visualisation of the raw accelerometer signals from the raw Hunting Tooth Average and the recomposed Planet and Carrier signals, as shown in Figure 3, where we note that there are clear differences in the accelerometer signal over time. This led us to pursue a data driven approach where we windowed the signals – conceptually this appealed as the averages are in the angle domain so we can isolate phase angle effects – and computed representative statistics for the windows.

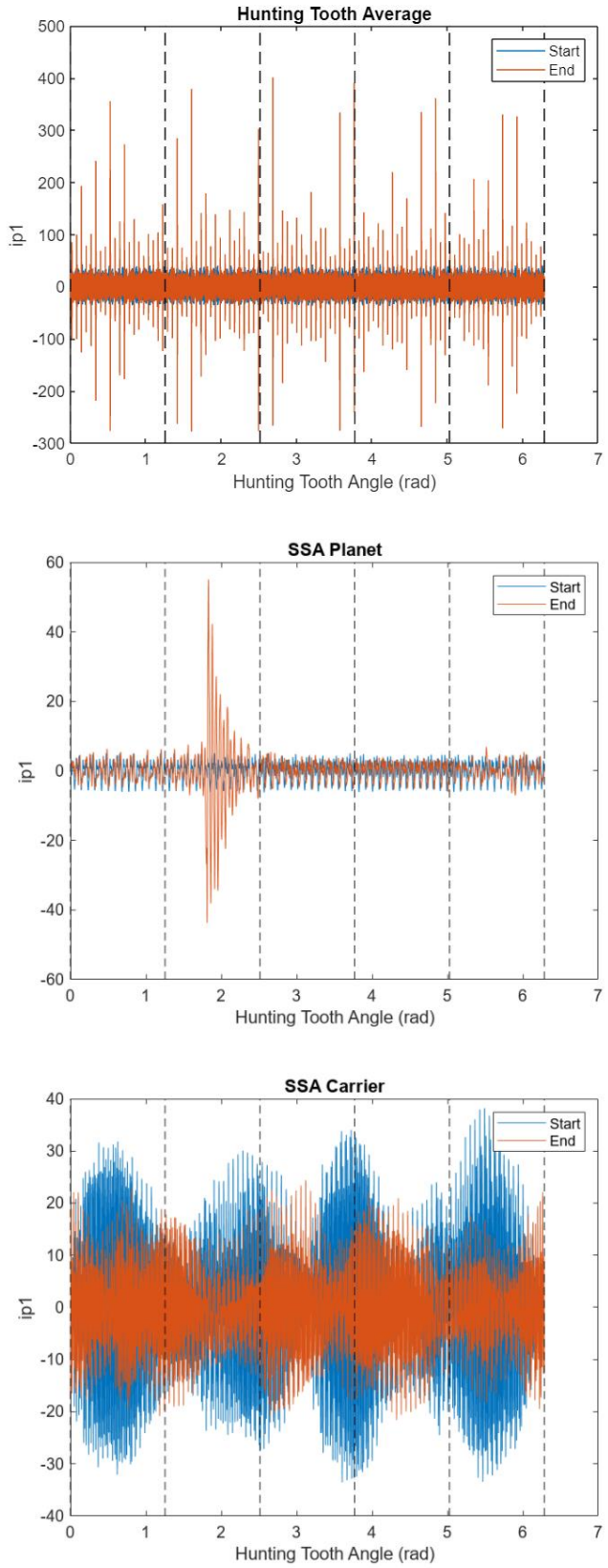

Figure 3 – recomposed SSA Planet and SSA Carrier signals showing a measurement at the start, blue, and end, red of the experiments.

The statistics computed for each window and each accelerometer channel were split into:

1. Regular: Mean, Standard deviation, Skewness, Kurtosis, Peak to Peak interval, signal RMS, Crest Factor, Shape Factor, Impulse Factor, Margin Factor, Energy; and
2. Spectral Kurtosis: Mean, standard deviation, skewness

Which resulted in ~900 signal channels. We then ranked these for "feature importance" based on the smoothed monotonicity of the signals, which reduced the channel count to approximately 40. Interestingly, the majority of these signals were derived from the hunting too channel rather than the averaged and reconstructed Carrier and Planet signals.

We then undertook a principal component analysis to further reduce the 40 channels to the first three and visualised these as a three-dimensional scatter coloured by the measurement sequence, as shown in Figure 2.

Finally, we used a Gaussian Mixture Model cluster method to split the three principal components into two clusters, which we interpret as:

1. Pre-crack growth stability
2. Crack growth period

The final failure acceleration phase of the crack growth was estimated directly from the PCA where the last few points accelerate away from the second cluster, as shown in Figure 2.

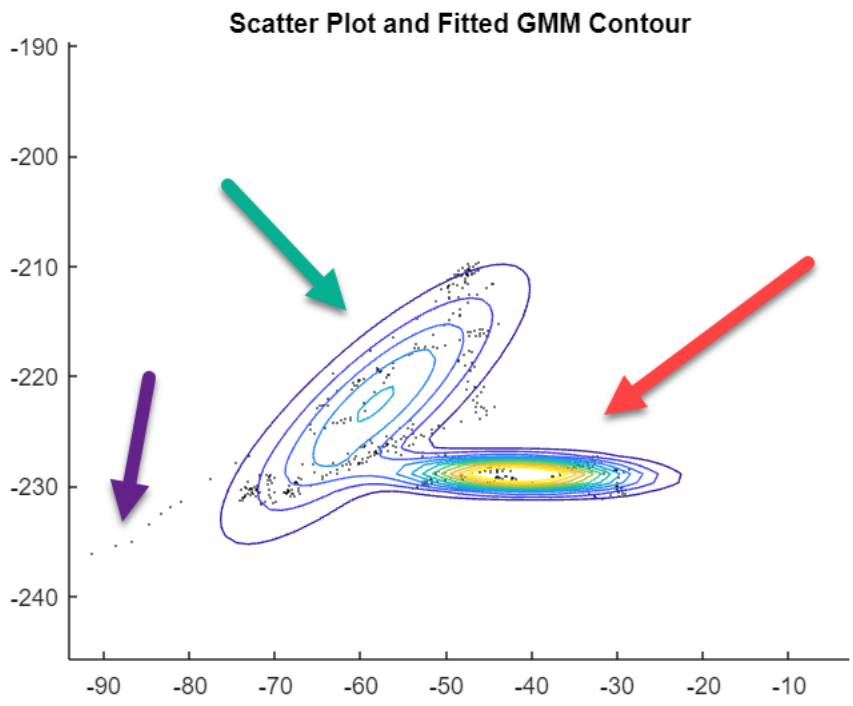

Figure 4 – Gaussian Mixture Model showing the first stable cluster, with high confidence in the red arrow; the second unstable cluster group highlighted in green arrow and the final acceleration away from the clusters in the failing phase shown with the purple arrow.

7. Supplement Information

Nil