In-process Monitoring of Automated Carbon Fibre Tape Layup using Ultrasonic Guided Waves

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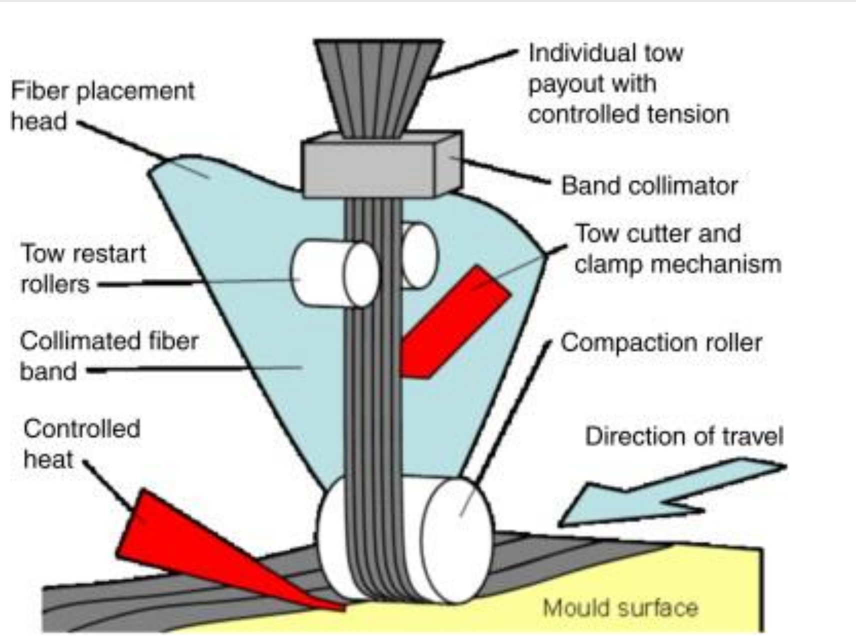
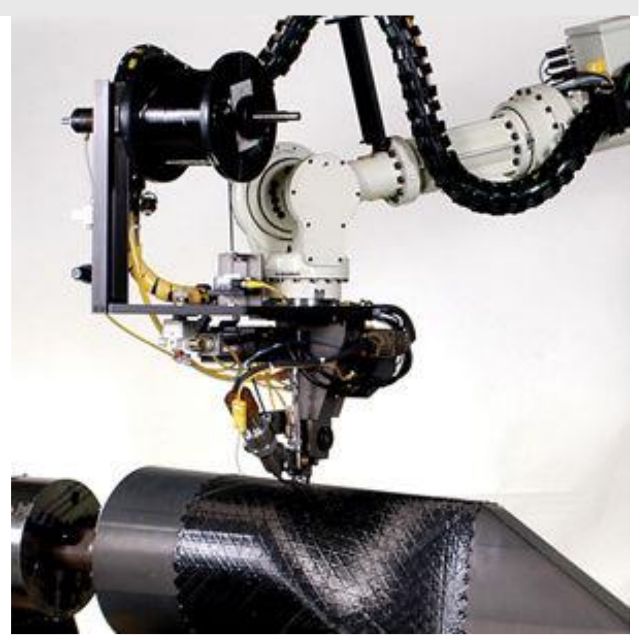
Automated Tape Laying

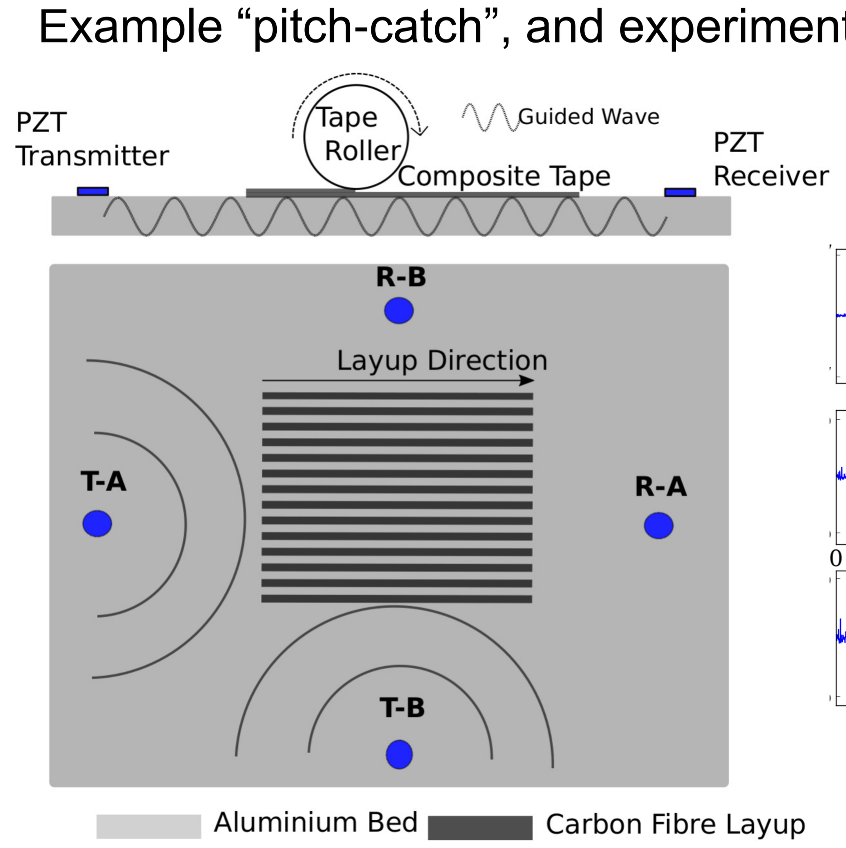
- Automated Tape Laying, industry standard for manufacturing of high strength composites with complex shapes and complex layup patterns
- Strength of final manufactured composite easily compromised by defects, such as Foreign Object Debris (FOD) or delamination
- Study investigates use of guided waves for monitoring this process with aim of detecting defects



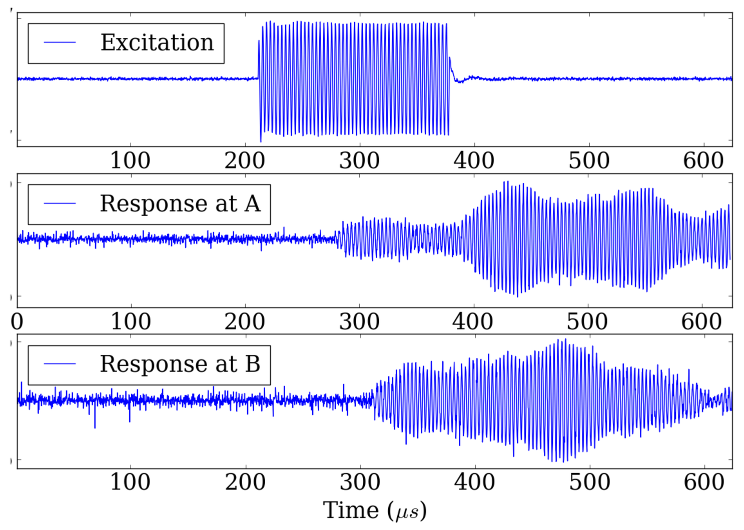


Ultrasonic guided waves

- Guided Waves are well suited to the problem of monitoring across large distances, compared to bulk waves which attenuate fast in a material
- They are an active technique, relying on a transceiver and a receiver
- Example "pitch-catch", and experimental setup below:

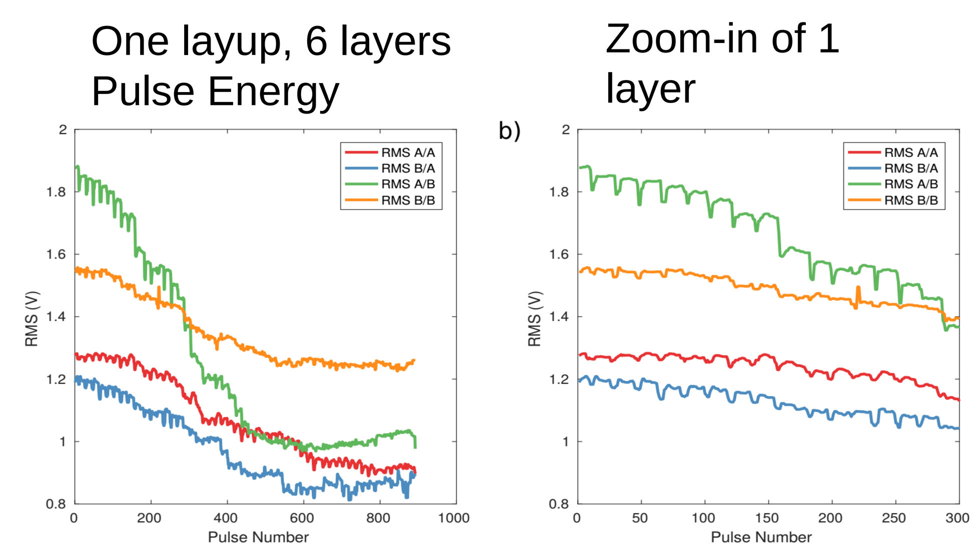


Tone burst of 300kHz:



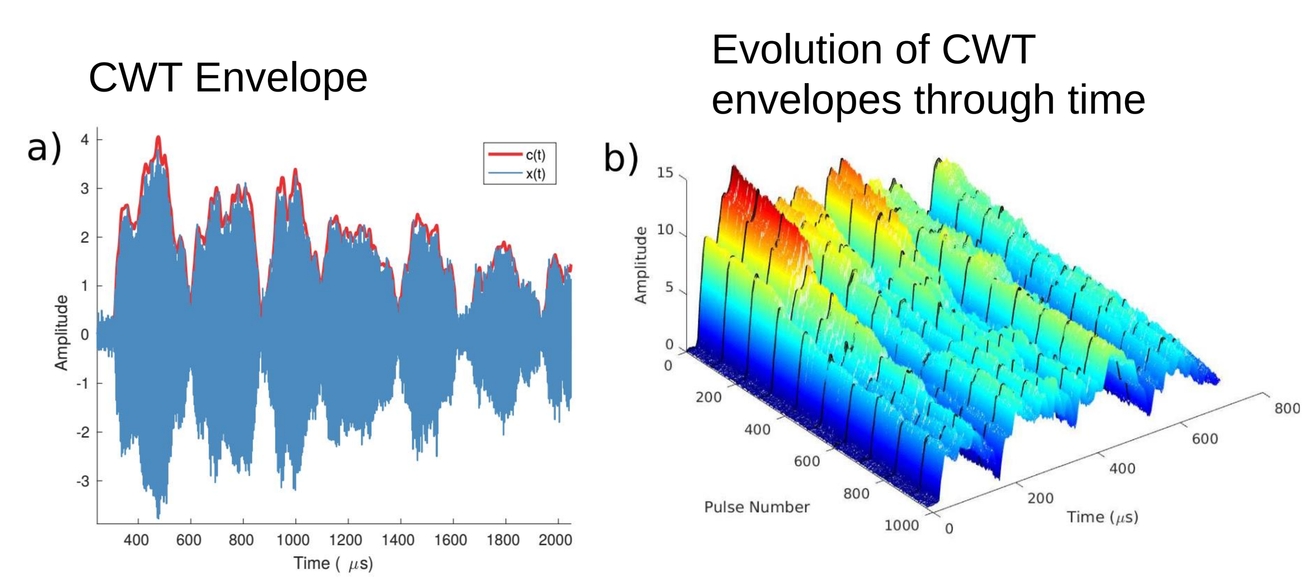
Data processing challenges

- Energy in received pulses shown above, indicates that wave propagation characteristics change continuously, due to:
  - Application of resin
  - Roller contact
  - Temperature changes



- More detailed processing is required to capture the fast changing dynamics of the wave propagation process, medium term dynamics of roller application, and longer term trend of cumulative resin application

Continuous Wavelet Transform



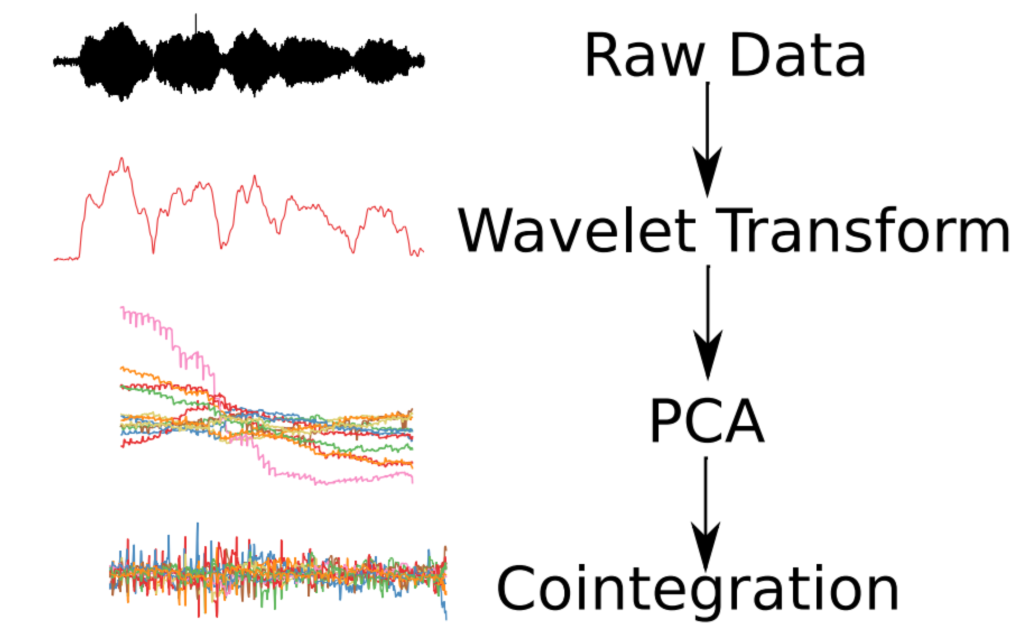
- Continuous Wavelet Transform (CWT) provides an efficient way of characterising the short term dynamics of the pulse. They create a feature that can be modelled across longer term dynamics
- CWT is still a high dimensional feature, and does not lend itself to multivariate statistical analysis, required for defect detection. Further compression of this can be achieved through Principal Component Analysis (PCA)

Cointegration for trend removal

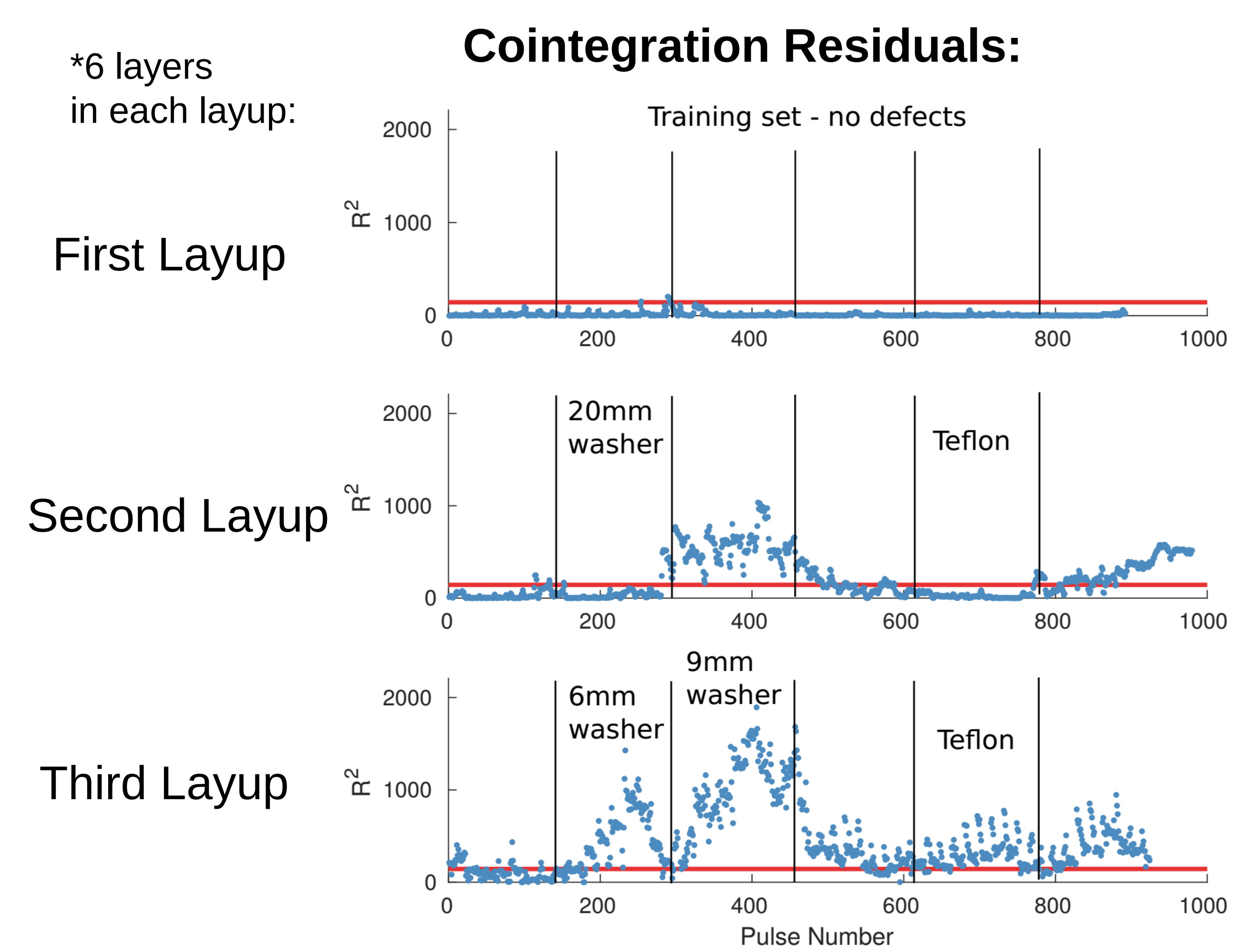
- PCA reduces the CWT envelopes to 3 features per channel. There are four transmission channels. This results in a 12 dimensional vector **Y**.
- Cointegration is used to remove the common trends found in **Y**.
- This is a method rooted in Econometrics, which aims to find a vector set $\boldsymbol{\beta}$, that reduces **Y** to a stationary process through a linear transformation:

$$\boldsymbol{\beta}'\mathbf{y}_t = \beta_1 y_{1t}, \ldots, \beta_n y_{nt}$$

Overall methodology



Results and conclusions



- Three layups were carried out, one free of defects, used to train the cointegration model, and two with seeded defects. Small washers emulate FOD, while thin teflon patches emulate delamination.
- Characterising a layup process, with all the operational variations involved, is a complex task. Detecting defects here is a highly subtle problem
- Residuals encoded in the cointegration vector, $\boldsymbol{\beta}$, are able to discern defects clearly, as shown in figure above.
- Results are highly encouraging, and show that this novel approach is feasible, though it requires a high level of data processing to model the process.