Damage Detection of Operating Wind Turbine Blades and Towers Using Signature Distances

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Damage Detection

Structural Health Monitoring

The process of implementing a damage detection and characterization strategy for engineering structures.

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- Other questions:
  1. How many sensors are needed?
  2. Where should the sensor be located?

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- Problem: Baselines hard to establish due to varying:
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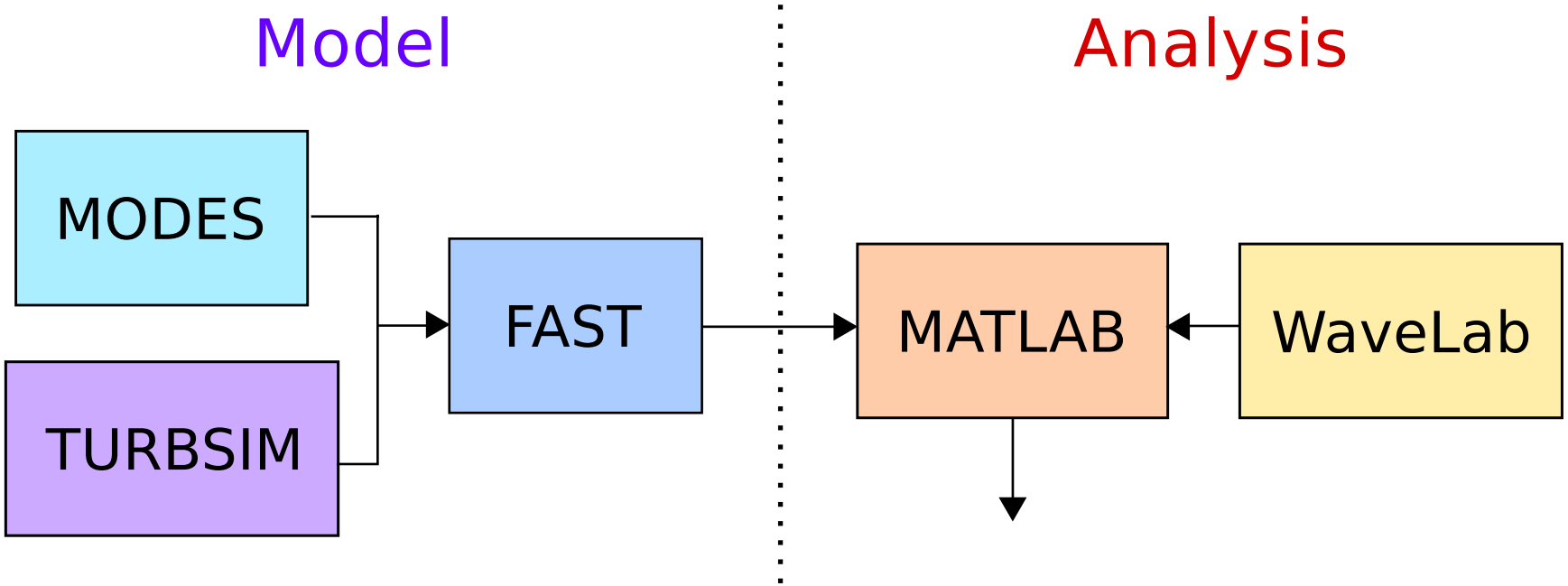
  - Loading
- Solution: Methods were developed which are uniquely affected by the damage
  - Tower: **shutdown maneuver** is analyzed in the **time domain**
  - Blade: **normal operation** is analyzed in the **frequency domain**

Codes



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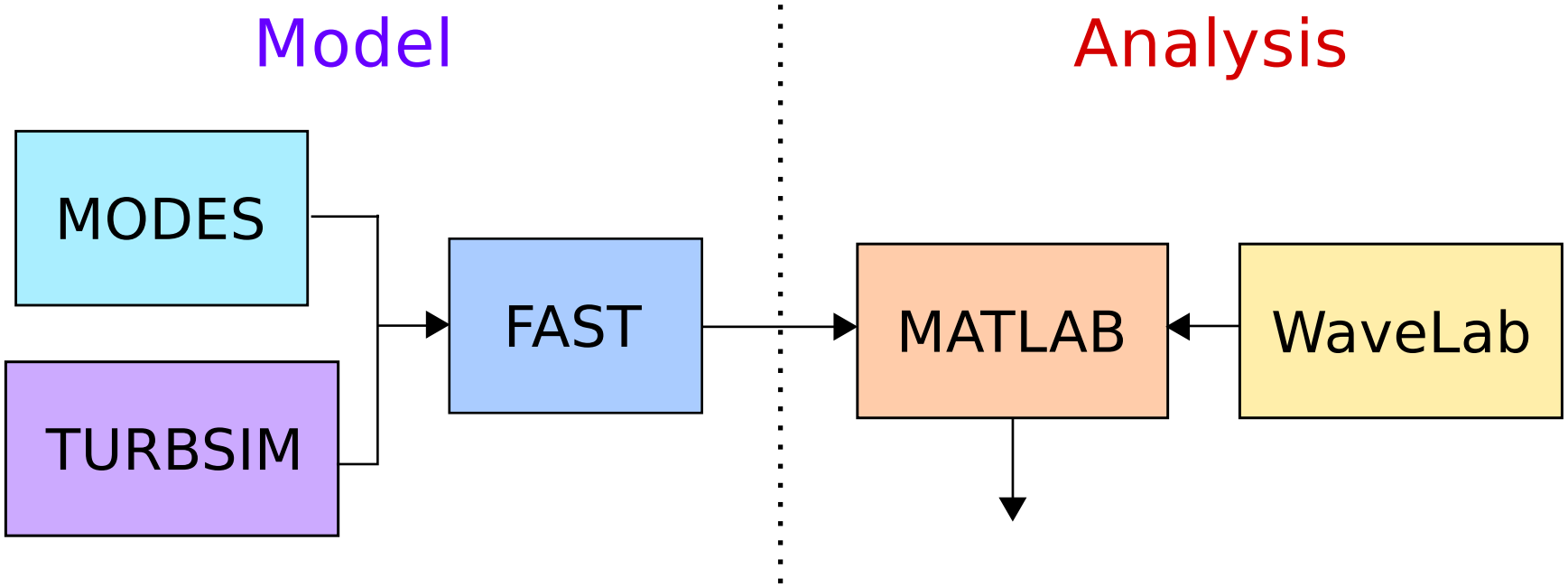

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  - Dynamics of the: tower, blades, generator, gearbox
  - Control systems: pitch, yaw, brakes
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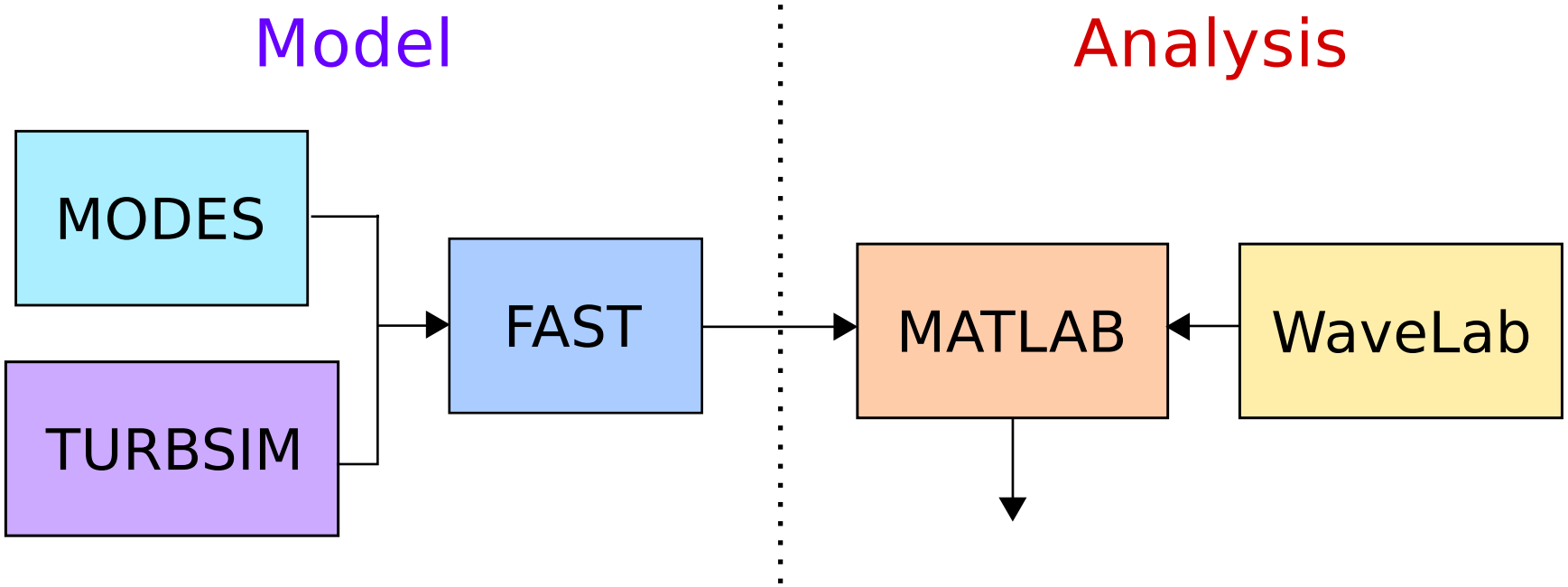

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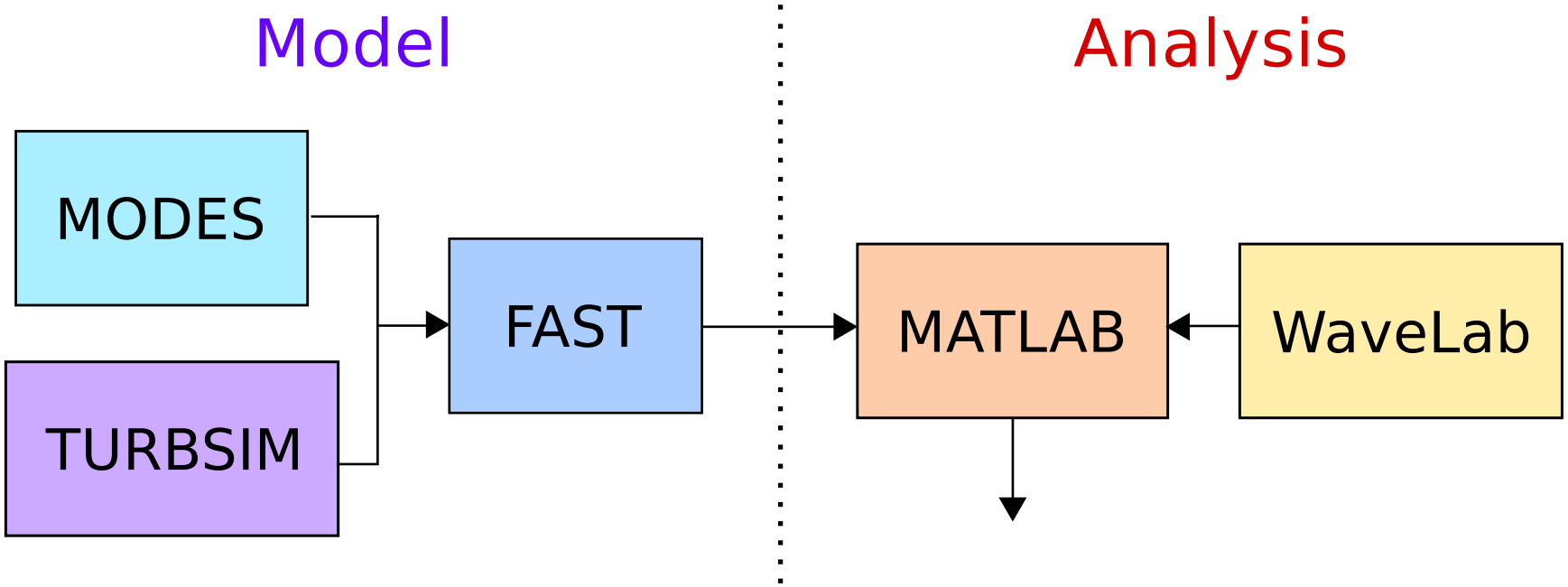

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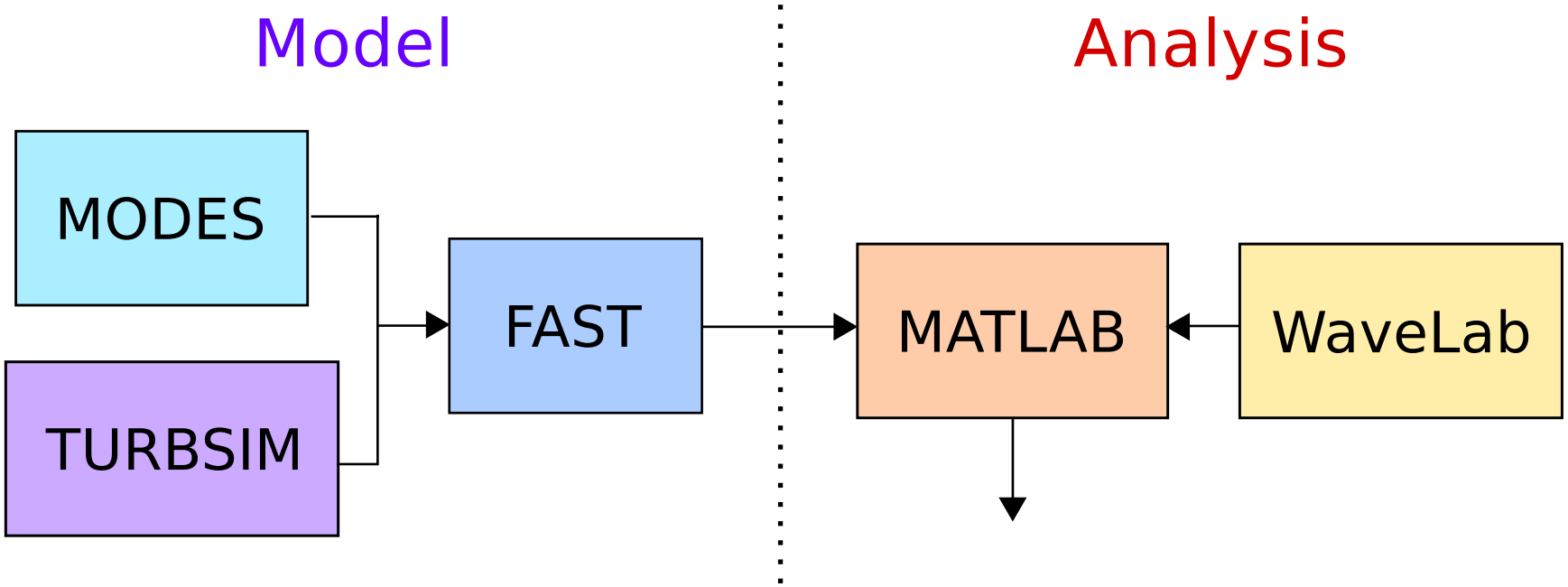

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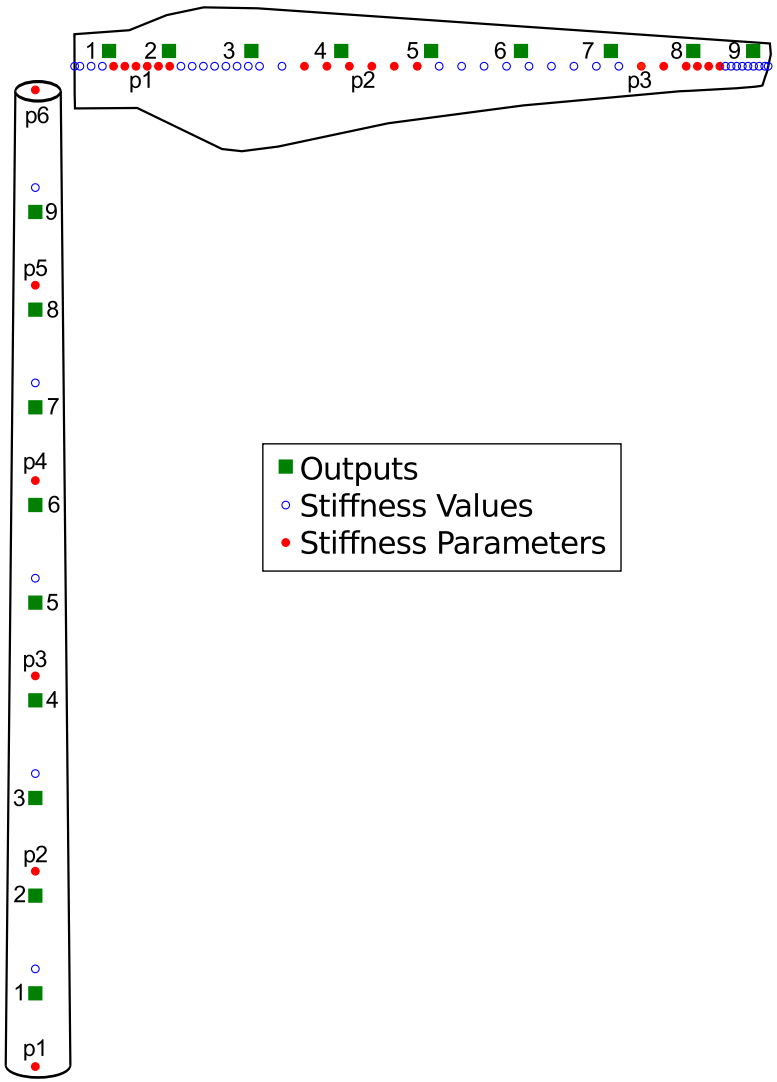
- **WaveLab:** Open source MATLAB toolbox

Model

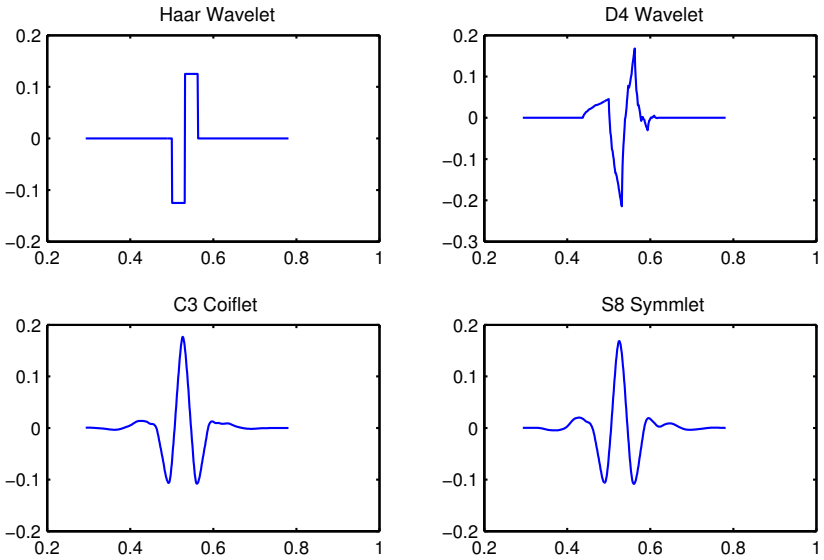
- NREL 5MW reference offshore wind turbine
- 63 m blades
- 80 m tower
- Pitch controlled
- Full field turbulent wind
- Distributed parameter systems
- Damage = a reduction in stiffness
- **Outputs:** Accelerometer locations
- **Stiffness Values:** Stiffness is specified
- **Parameters:** Damage is modelled

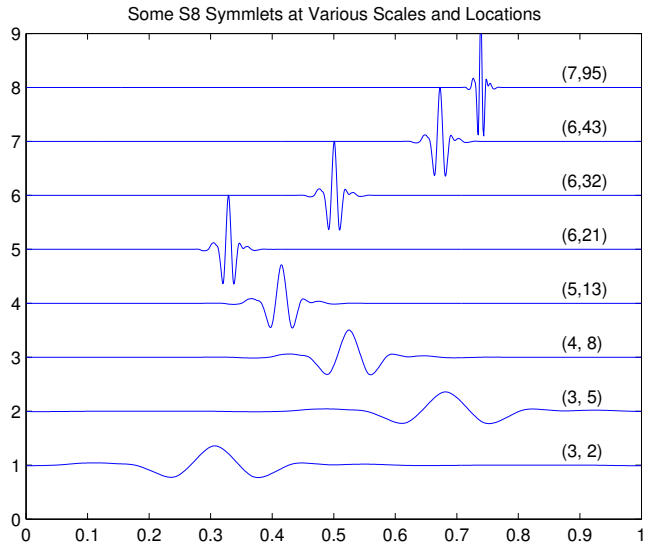


Methodology

- 5 wind profiles are considered
- For each wind profile healthy and faulty conditions are simulated
- The healthy turbine in Wind 1 is the baseline
- Signature distances are calculated by comparing the baseline to the other signals
- Result is healthy and faulty signature distances
- The faulty cases consistently result in a larger signature distance indicating that damage is detectable

What are wavelets?





- Little waves, Area under curve is 0
- Are convolved with a signal (like Fourier Analysis)
- Are stretched (scale) and translated (time)
- Benefits of Wavelets:
  - Can detect local events in a signal
  - Provides multi-scale resolution (multi-scale smoothing)
  - Turns a 2 dimensional signal into a 3 dimensional surface (enhanced resolution)

Wavelet Transform Example

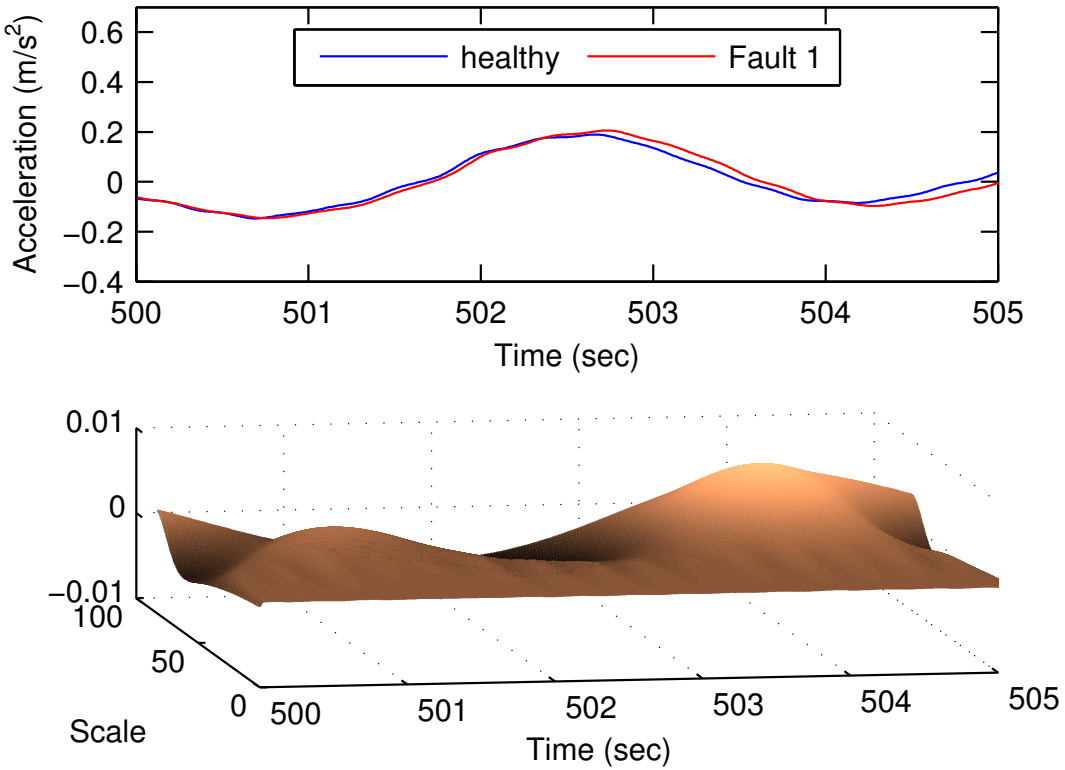
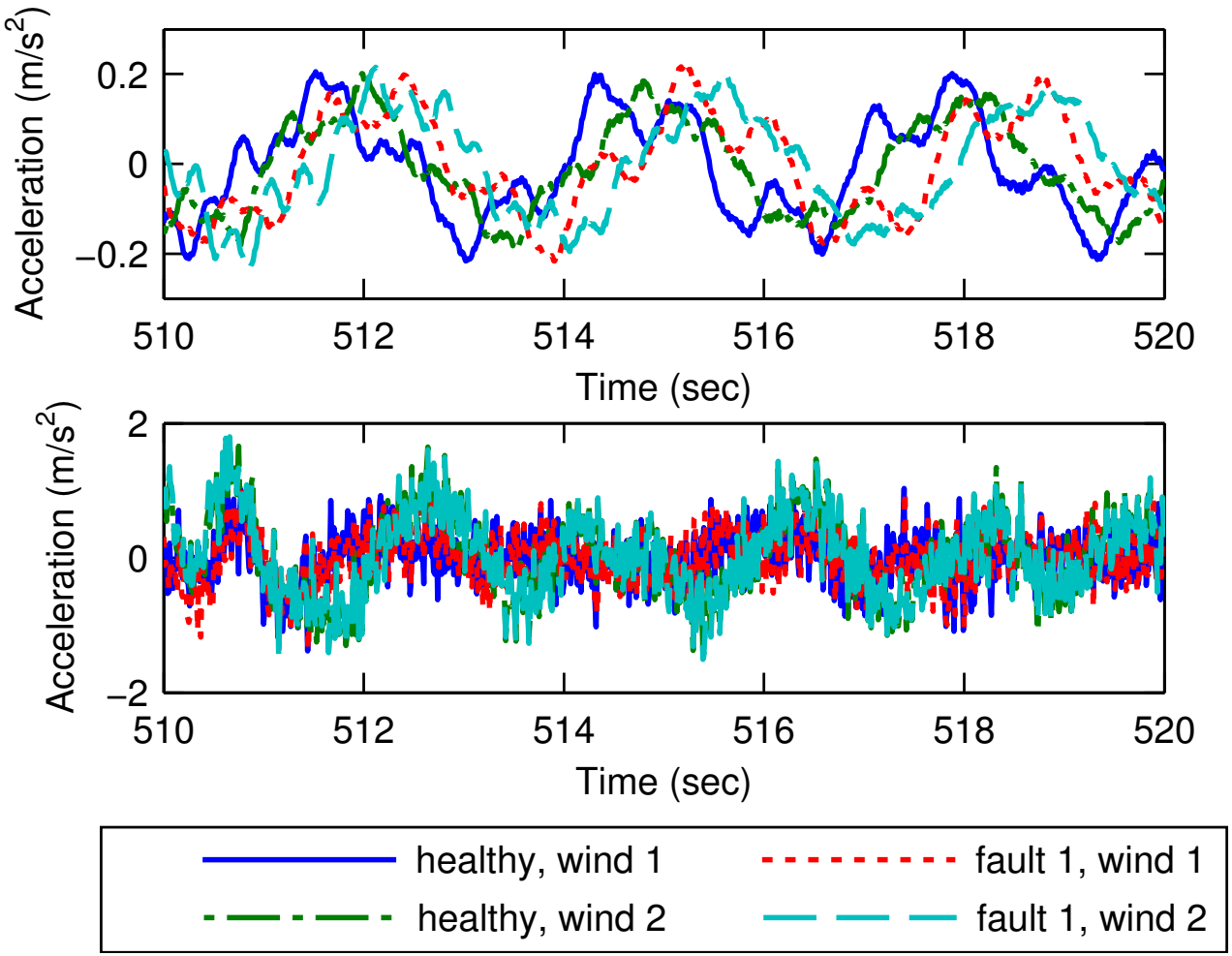
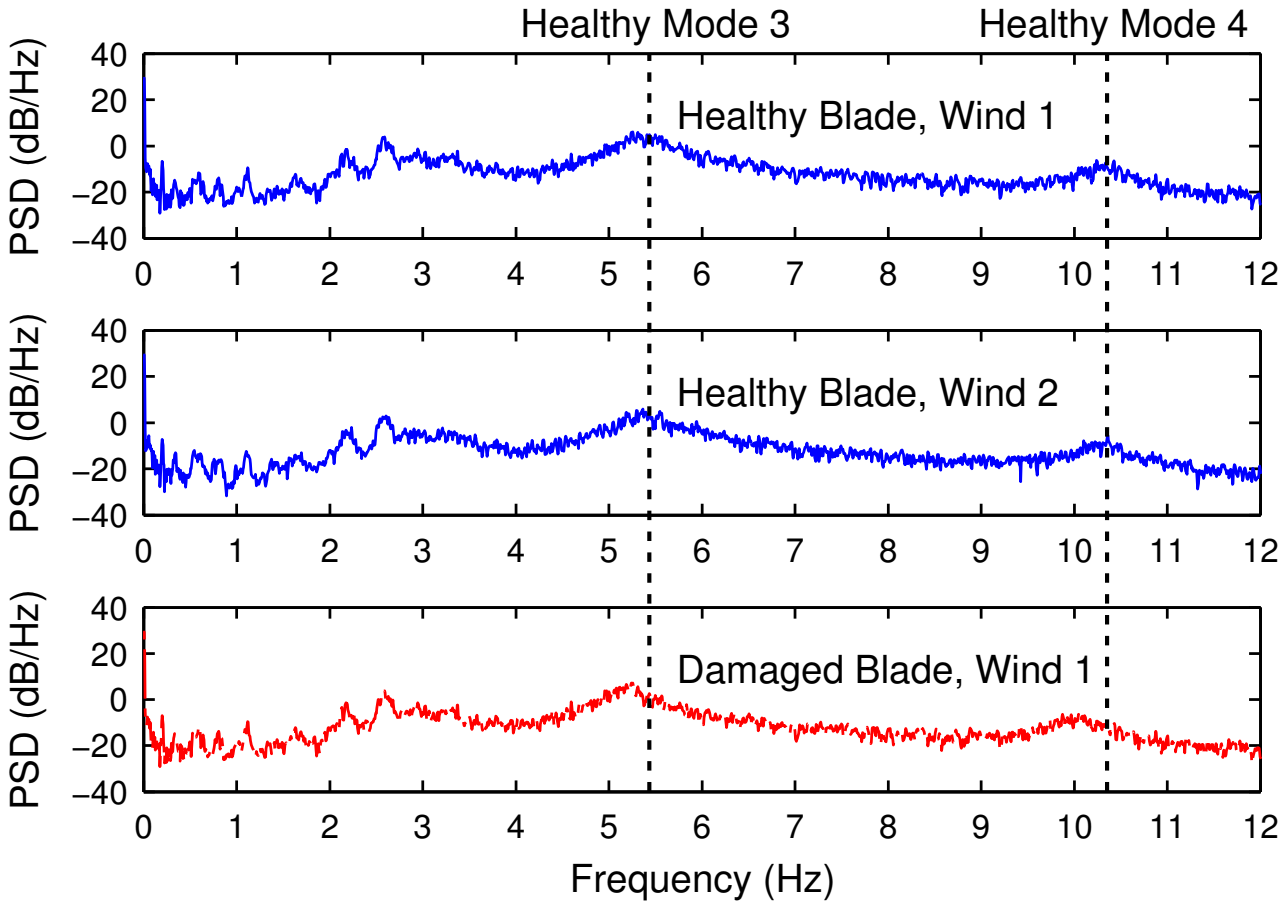


Illustration of the enhanced delineation of two similar signals (top) by the differential wavelet transform (bottom) which accentuates the minute differences between the two signals

Response Magnified

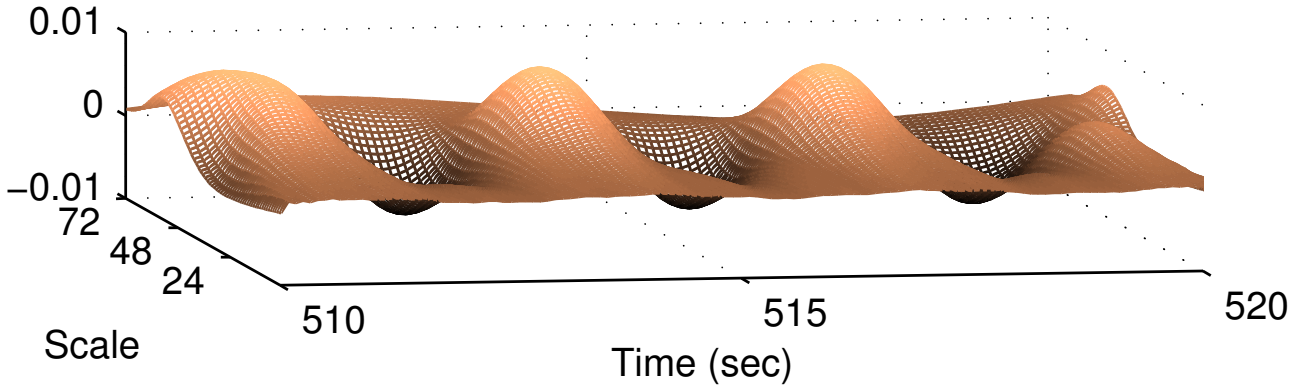


Acceleration of the tower at location 7 (top) and the blade at location 7 (bottom) after the brake maneuver is performed



- Distinct difference found in the third and fourth mode

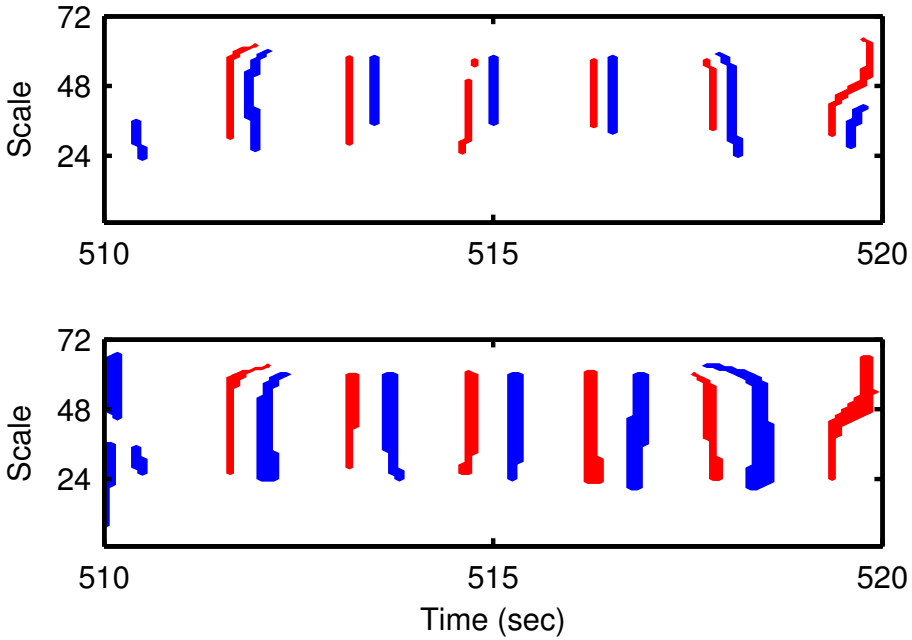
Definition of a Change Signature in words

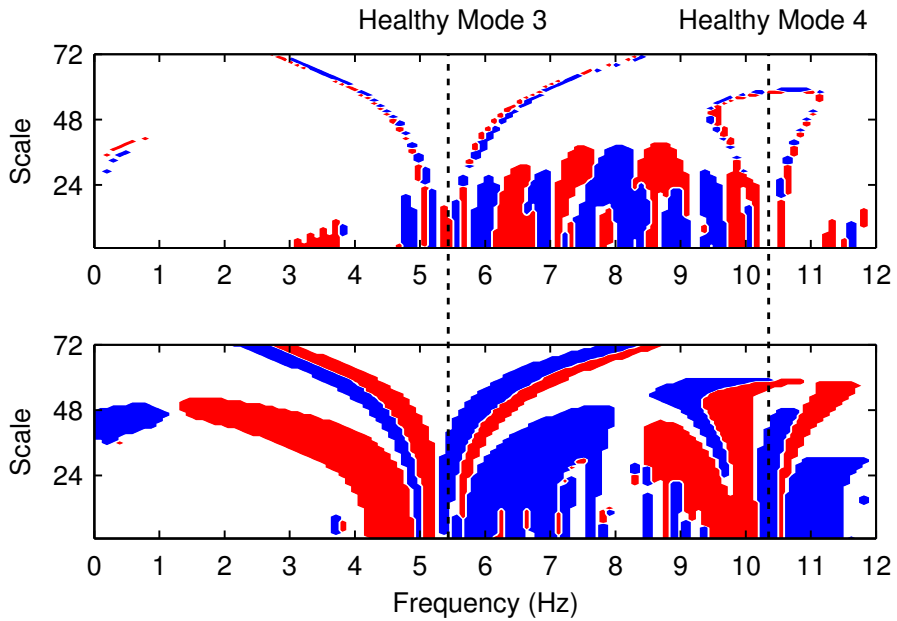


Gauss WT of tower acceleration at location 7 after the shutdown maneuver is performed

- WTs of the baseline signal is compared to a different signal
- Locations where the ratio of the two WTs is above a *dominance factor* are flagged
- This results in a change signature

Change Signature Example

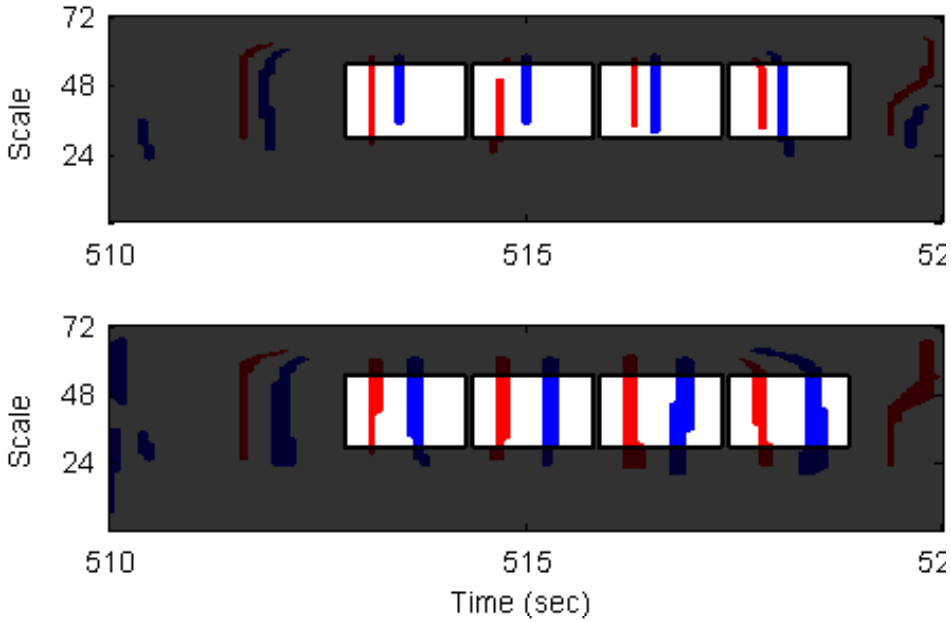


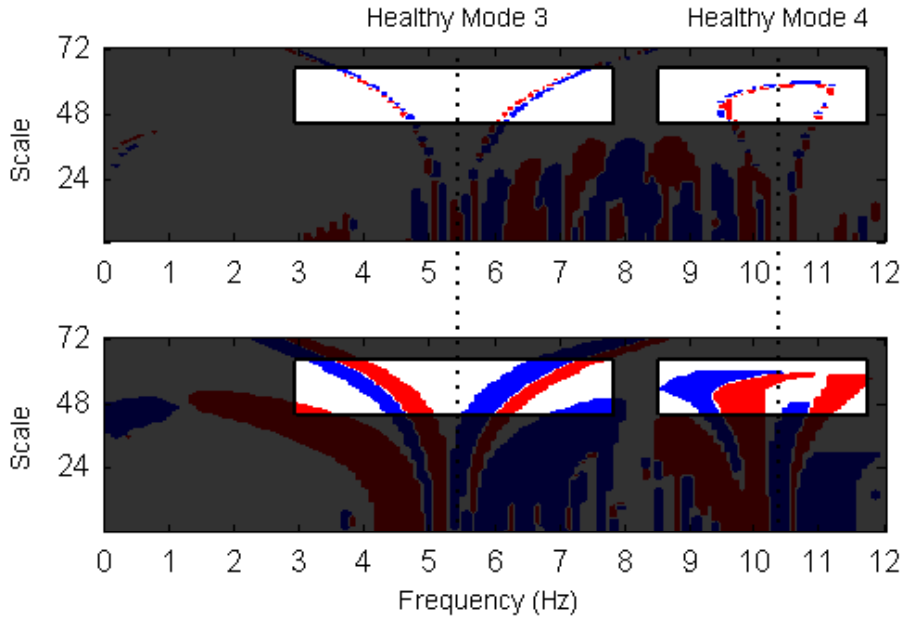


- Tower Change Signatures
- Top: Healthy to Baseline
- Bottom: Faulty to Baseline

- Blade Change Signatures
- Top: Healthy to Baseline
- Bottom: Faulty to Baseline

Windowing of Change Signatures





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Tower Signature Distances

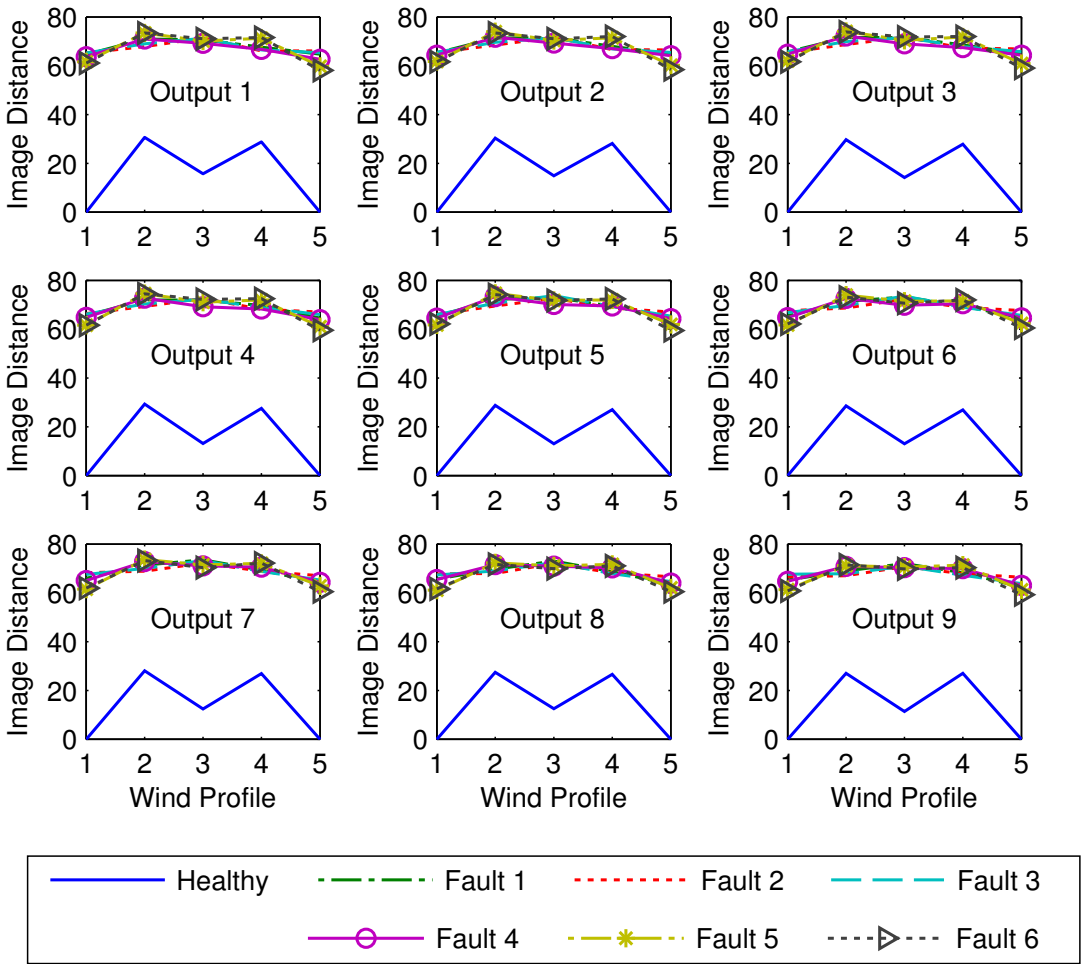

Image distances of the acceleration time histories at 9 output locations of the tower obtained for the healthy tower and a 5% damaged tower with five different wind profiles having a mean speed of 12 m/s

Blade Signature Distances

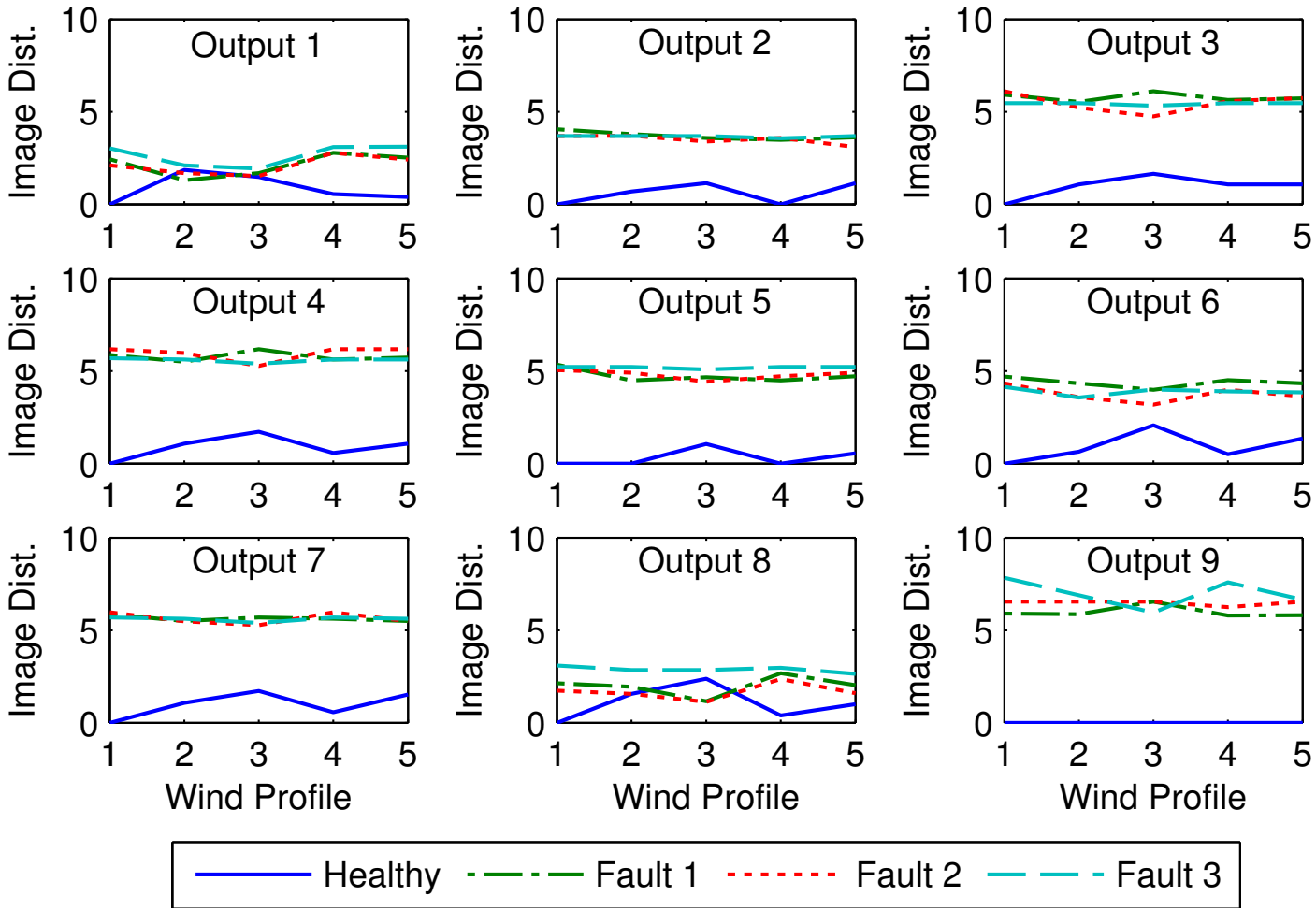

Image distances of the change signatures in the proximity of the third mode for the healthy and 30% damaged blade by each of the nine blade output locations

Conclusion

- Damage is detectable using these methods
- The tower damage method is not sensitive to the output location
- Blade damage is sensitive to the output location
- Future work
  - Develop a method for determining the location of damage
  - Validate the method using test data
  - Choose an optimal number and location of sensors

THANK YOU

Thank you for attention!

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