Wind Turbine Operational Modal Analysis Algorithm Comparison

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Introduction

Bellacorick Wind Farm, one of Ireland's oldest wind farms, provides a valuable case for analyzing end-of-life wind turbines through structural health monitoring (SHM) [1]. SHM aims to autonomously assess structural integrity by analyzing accelerometer data to identify natural frequencies, peak frequencies, and mode shapes [3]. This data can help detect damage by tracking changes in a structure's vibrational characteristics. While operational modal analysis (OMA) has been widely applied to various structures, such as bridges and buildings, its application to onshore wind turbines remains underexplored. This study analyzes Frequency Domain Decomposition (FDD), Variational Mode Decomposition (VMD), and SSI-COV algorithms to evaluate their effectiveness in analyzing accelerometer data from Bellacorick Wind Farm [8][9][10]. By comparing these methods, this research aims to develop a framework for how an algorithm can be selected to perform an in-depth OMA of wind turbine tower accelerometer data.

Methodology

The study used accelerometer data from eight sensors installed in a wind turbine tower at Bellacorick Wind Farm. Data preprocessing involved organizing the sensor readings into a matrix, applying a Butterworth notch filter, removing mean bias to center the data, and using a Hamming window to minimize edge effects [11]. A subset of the processed data, spanning samples 200,000 to 600,000, was extracted for testing. Three algorithms—Frequency Domain Decomposition (FDD), Variational Mode Decomposition (VMD), and covariance-driven stochastic subspace identification (SSI-COV)—were applied to analyze the data. FDD required data formatted in an Excel file, VMD processed one sensor at a time with averaged results, and SSI-COV used the full sensor matrix to compute modal frequencies and mode shapes.

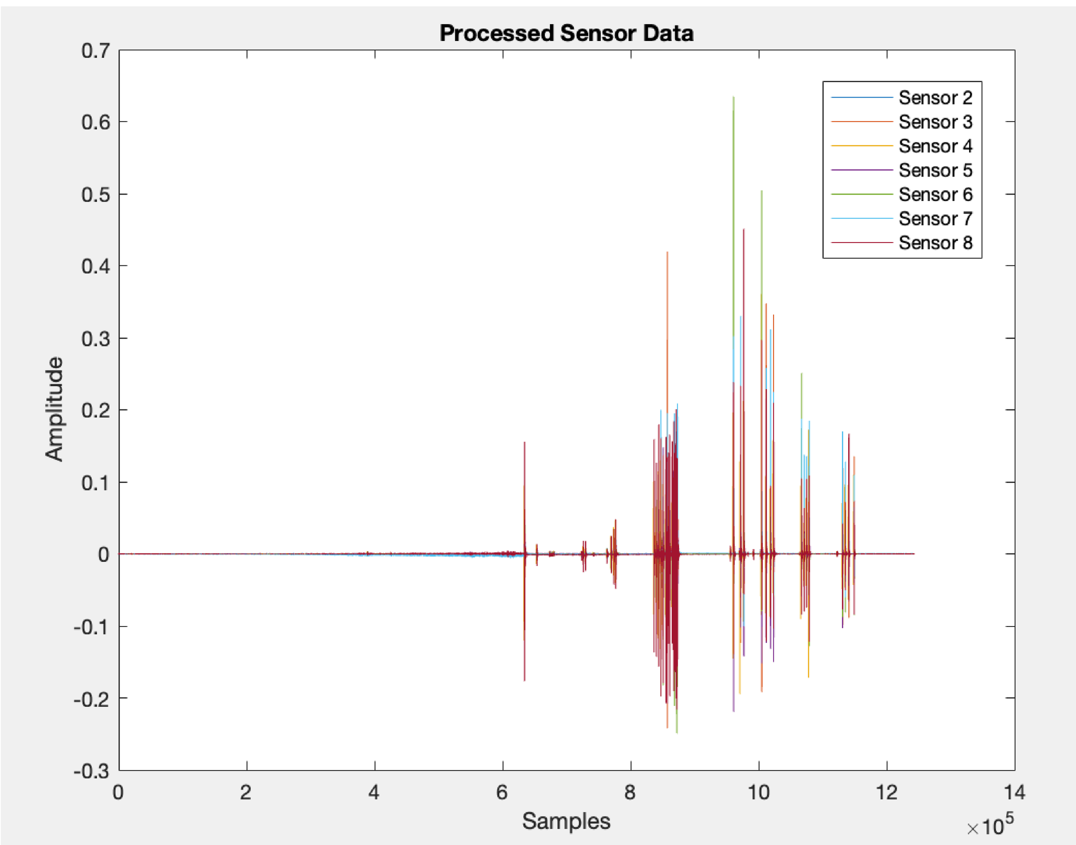

Figure 1: Processed Data

Results

The preprocessing code can be applied to additional data sets from Bellacorick.

The analysis revealed that the FDD and SSI-COV algorithms produced consistent modal frequencies, while VMD exhibited computational limitations and inconsistencies, particularly with larger datasets. The expected frequencies from prior impulse hammer studies (approximately 1 Hz, 9 Hz, and 17 Hz) were not observed, with FDD and SSI-COV providing similar but higher frequency results. FDD proved to be reliant on MATLAB's deprecated `getrect` function, which is no longer recommend by MatLab's documentation[12]. Due to this reliance, the algorithm had to be edited to use the `getinput` method, which causes high levels of human error. OMA demonstrated the best performance for analyzing large datasets, making it the most reliable method among the algorithms tested.

Mode	FDD (Hz)	VMD (Hz)	OMA (Hz)
Mode 1	7.95	9.31	16.91
Mode 2	20.39	149.61	20.76
Mode 3	42.51	288.02	56.80

Figure 2: Modal Frequencies

Discussion

The FDD algorithm was user-friendly because it takes data input as an excel file, but it was hindered by its reliance on the outdated MATLAB `getrect` function. The VMD algorithm faced challenges with large datasets because of the nature of it splitting the 1D input vector into different signals. VMD required individual sensor processing, as 1D vectors, limiting its scalability and ease of use as additional code was needed to average every sensors modal frequency. The SSI-COV algorithm proved most reliable for analyzing larger datasets, providing results consistent with FDD. However, none of the algorithms identified frequencies matching those from previous impulse hammer studies, indicating potential differences in the datasets or analysis methods. The process of testing these algorithms can be applied to others. All three of these algorithms were able to take acceleration data as a direct input, suggesting the ability to use acceleration data for other algorithms published in MathWorks.

Operational modal analysis with automated SSI-COV algorithm

Version 2.5 (2.37 MB) by E. Cheynet

The modal parameters of a line-like structure are automatically identified using an SSI-COV algorithm applied to ambient vibration data

https://windengineeringuis.github.io

Variational Mode Decomposition

Version 1.0.0.0 (4.33 KB) by Dominique Zosso

Variationally decompose a 1D signal into k band-separated modes.

Frequency Domain Decomposition (FDD)

Version 1.0.0.0 (7.57 MB) by Mohammad Farshchin

This MATLAB code implements the FDD technique for output-only modal analysis

Figure 3: Algorithms Analyzed

Conclusion

Bellacorick Wind Farm provides a valuable case for exploring structural health monitoring techniques. Although none of the tested algorithms matched expected frequencies from previous studies, FDD and SSI-COV showed similar results, making them promising for future analysis. Further refinement and validation of these methods will be crucial for developing a robust framework for wind turbine modal analysis.

Future Work

Future work will focus on testing additional algorithms to validate the findings and refine methodologies for operational modal analysis. Efforts will include reworking the FDD algorithm to improve its usability, analyzing more datasets with FDD and SSI-COV to confirm their reliability, and exploring other VMD and SSI-COV implementations.

Once the most effective algorithms are identified, they will be applied to broader datasets to determine the natural frequencies of wind turbine towers with greater temporal specificity. Once a greater specificity of natural frequency is created, a system can be engineered which recognizes with high success the difference between changing natural frequency and system noise. This tool will then be developed into an automated structural health monitoring system.

References

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