Using Audio-Data for Anomaly Detection in the Fatigue Test of a Composite Tidal Turbine Blade

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Abstract. FastBlade is a research facility for testing large-scale composite and metal structures. Fatigue tests run on tidal turbine blades measure the mechanical response of a blade subject to the number of loading cycles that mimic the ones it will experience over its lifetime of a subsea deployment. To maximise its throughput by running the facility uninterruptedly, unmanned operation of the site should be possible. One of its key enablers is anomaly detection. Microphones are used as a non-specific and affordable sensing method. Using the audio data, we applied a Fast Continuous Wavelet Transform to extract the patterns recorded during normal and abnormal operations. These outputs are used to train a neural network autoencoder (NNA). The original image is reconstructed from the compressed vector in the latent space (LS) of the NNA, and the loss is computed to detect and quantify anomalies. The study's findings demonstrate the success of using audio data to detect short-lived anomalies despite limited information about the critical assets in the set-up and can be easily extrapolated to other systems.

Introduction

Anomaly detection (AD) aims to identify patterns in a particular dataset that do not conform to the expected behaviour. Considering data collected in an industrial or experimental process, AD is crucial in enabling advances in system automation. By identifying the periods of anomalous operation, the relevant data sets can be analysed to examine the nature of a fault. Alternatively, AD algorithms can run in real-time and give a warning of a persistent anomaly which might prompt a site operator to bring the process to a halt. This paper focuses on the operation of FastBlade, which is a research facility for testing large-scale composite and metal structures [1]. In this study, we developed a feasible way of determining real-time anomalies occurring in the facility. The solution developed should be seamlessly transferrable between systems operating in both experimental and industrial settings.

System Characteristics

FastBlade. The system available at FastBlade consists of a reaction frame on which the specimen under test is mounted, four Digital Displacement® Pumps (DDPs), four electric motors, four actuators, a cooling system and data-logging infrastructure (see Fig. 1). DDPs allow a fully-controllable, bi-directional flow, which is a crucial design feature of the energy-recovery system. We focus mainly on the fatigue test operation, in which the actuators cyclically deflect a specimen and log changes in the main mechanical properties (i.e. strain). The loads can arrive at one MN during this operation, and the maximum moment is five MNm [1].

System Objectives. By conducting the fatigue tests described on tidal turbine blades, the wear of the structure can be simulated when the number of loading cycles performed is equivalent to the number of cycles it would experience in water over a given period. The design of the system allows for powering the actuators independently, exerting custom time-varying loads (e.g. sine- or triangular waves). In order to maximise the throughput of the facility, it should run continuously to accelerate the test, thus requiring an AD system.

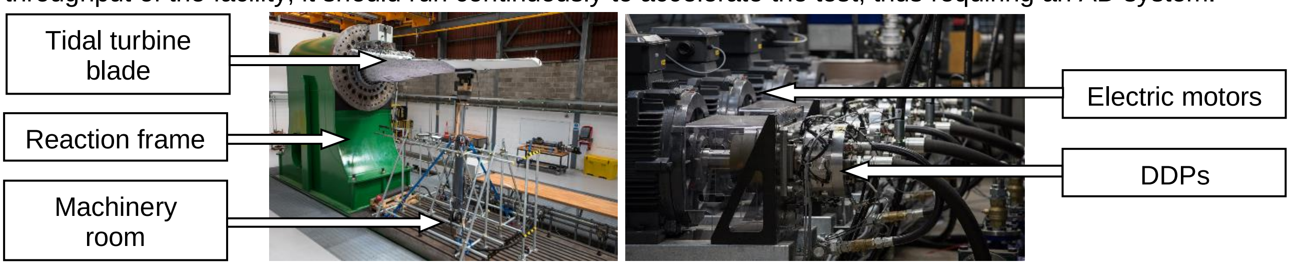

Fig. 1. The FastBlade main test hall (left) and the machinery room located downstairs (right) [1].

Resources

Anomalous Data. A wide variety of data was collected during a fatigue test. Among a series of anomalous behaviours, we identified, the most serious one was the loss of synchronisation of the pumps, evident in both actuator pressure and load recordings. The event occurred multiple times and, lasting for around one second each time, witnessed the pumps operating out of phase. This anomalous behaviour leads to unwanted loads impacting the specimen, threatens the system's stability and increases the wear of the pumps, reducing the time until the next maintenance.

Instrumentation. Considering the system's characteristics, a microphone is the most suitable sensor for this application. Although it should be possible to detect anomalies using the sensors already present in the system, microphones offer a non-specific solution sensitive to faults of different natures. The solution should be easily transferrable to other systems since microphones tackle the problem of unknown asset internals. Despite being low-cost and low-power devices, they are also characterised by a wide bandwidth. The microphone used was an IMP34DT05 by STMicroelectronics (working at a rate of 48 kHz). During the test, the microphone was installed directly in the test hall, yet outside of the machinery room, to avoid clipping the waveform due to the high amplitude of the test sound.

Method

Anomaly Detection (AD). The AD algorithm should be able to pick up anomalies from several different assets on-site. Moreover, we face the problem of limited information due to trade secrets protecting many of the operation details of the outsourced assets, including the DDPs. Lastly, very little historical data exists since FastBlade is a new facility. However, literature shows successful anomaly detection algorithms can be developed despite considerable historic data scarcity [2].

Signal Processing. From a visual inspection, it is impossible to determine if or where an anomaly occurred as there is no apparent effect on the recorded waveform. Thus, signal processing exposes anomalous behaviour in the data (e.g. through filters or using the frequency domain). Fast Fourier Transform is a commonly used technique to transfer efficiently into the frequency domain; however, it can only be applied to periodic and infinite signals [3]. Since, in our system, the specimen's behaviour changes over time, and the anomalies are short-lived, we cannot make such an approximation. We used Wavelet transform (WT) to solve this, which considers the signal in both time and frequency domains and is suitable for short, non-periodic signal variations. Although such a transition compromises information accuracy, the resulting signal representation allows us to extract features relevant to our analysis.

Neuronal Network Autoenconder (NNA). NNA is a machine learning technique in which two neuronal networks (NNs) join to first encode the input data into a vector of significantly smaller dimensions, the LS. Furthermore, a second NN decodes the LS back into the original input. The reconstruction error, computed using the input and output of the NNA, rises when anomalous data is fed into the model. Moreover, the anomalous data tend to be isolated in the LS regions. The resulting information flow is presented in Fig. 2.

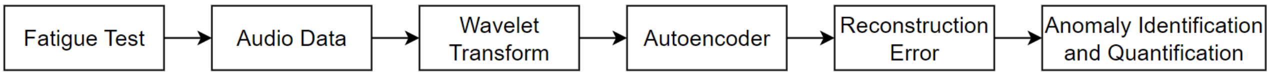

Fig. 2. The processing pipeline shows the steps between recording the test audio and anomaly detection.

Results

Fast Continuous Wavelet Transform (fCWT). Using the fCWT allows efficient approximation of the Morlet WT computation [3]. The signal analysis in both time and frequency domains reveals significant differences between audio data samples collected during regular and abnormal operation periods (see Fig. 3).

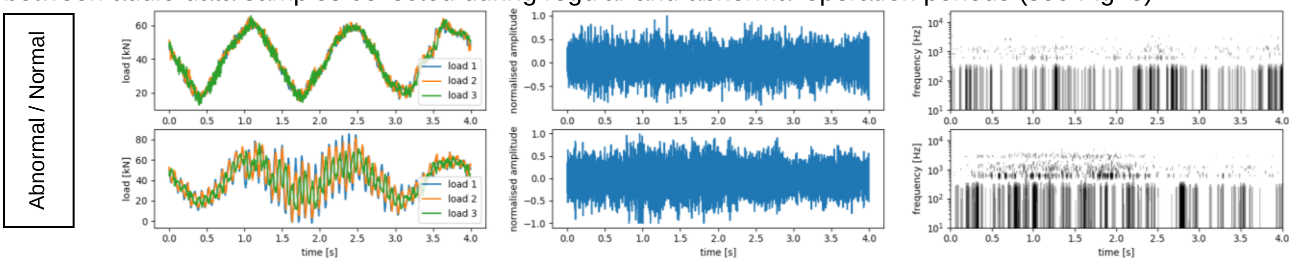

Fig. 3. System loads, microphone output and WT image for normal (top) and abnormal (bottom) operation.

Image Reconstruction. Representing the spectrograms from the fCWT as a grayscale image, the NNA was trained. Considering the signal in both time and frequency domains, anomaly detection comes down to image reconstruction and error calculation. Considering the dataset collected, the anomaly threshold is found experimentally, and a sigmoid function is used to estimate an anomaly's severity.

Conclusions

We identified a suitable method for AD which relies on the audio signal and requires minimal financial investment. Moreover, we produced an NNA-based pre-trained algorithm using a 2-D fCWT input generated from the audio data, suitable for real-time AD in the operation of the experimental system.

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