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Identification of Wind Turbine Noise Through Signal Analysis

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Summary

The goal of wind farm noise audit techniques is to quantify the component of sound in an environment attributable to wind turbines. It is thus desirable to isolate times during which the noise levels that were measured contain a strong component of wind turbine noise. Additional methods of identifying these periods could help augment noise audit techniques and increase their effectiveness. It can be shown that various forms of signal analysis techniques are capable of detecting the presence of a wind turbine blade pass noise within a measured noise audit signal. Fast Fourier transforms, autocorrelations, and cepstrum analysis have all been evaluated, and each has been shown as a feasible method of wind turbine detection, potentially capable of assisting with wind farm noise audit techniques.

1. Introduction

The development of wind power and the installation of megawatt class wind turbines has continued to spread across the globe. Accompanying the proliferation of wind power are increased concerns over the environmental noise impact these turbines may have on their surrounding communities. To ensure regulation of established noise guidelines, jurisdictions such as Ontario have responded by more frequently requiring quantification of wind turbine noise through an acoustic audit. These audits should effectively measure the noise imission of a wind farm at nearby receptor locations under a range of wind conditions. This poses several challenges.

It is well known that a turbine's maximum noise contribution will typically occur while operating at higher wind speeds, and that increased wind can elevate average ambient noise levels. As such, ambient background noise can mask or obscure turbine noise levels, making it difficult to evaluate turbine noise contributions using traditional environmental noise audit techniques.

Turbine noise can rarely be distinguished from ambient background noise through analysis of overall sound level alone; sound level should be considered in conjunction with additional metrics. Some wind turbine noise audit techniques focus on identifying conditions that are conducive to wind turbine noise propagation, and attempt to control as many environmental factors as practical to ensure adequate quality of the measured noise data from wind farms. There is a need to better detect the presence of wind turbine noise in a given signal.

Although it can be difficult to identify the presence of wind turbine noise through analysis of sound pressure level, the presence of wind turbine noise in a signal can be inferred by other characteristics. Specifically, blade pass harmonics of wind turbine noise can be observed via spectral measurements, and time signal periodicity can be observed through autocorrelation. It was hypothesized that this character of wind turbine noise could be detected and used as an indicator of wind turbine noise in a signal. This paper explores the feasibility of fast Fourier transforms, autocorrelations, and cepstrum analysis as methods to help identify measurement data that contains wind turbine noise. This could be implemented to improve the quality of measured noise audit data sets, and could augment other promising wind farm noise audit techniques with the goal of better quantifying wind farm noise.

2. Experimental Design

2.1. Concept

As wind turbine noise in the audible frequencies is broadband, it can be difficult to identify wind turbine noise components within a signal by analysing the energy averaged sound pressure levels in a given spectrum. Wind turbines do, however, exhibit distinct, very low frequency blade-pass harmonics with a fundamental around 1 Hz, depending on the rated rotor frequency of the subject turbine. These blade pass harmonics can be visible in the spectrum of low frequency noise measurements, however, it is also feasible that they can be obscured by low frequency 'pseudo-sound' resulting from atmospheric turbulence. This could render the discernibility of these harmonics as low, or even negligible at times. Nevertheless, conditions should also occur when the turbine blade pass harmonics will not be completely masked. This suggests there is potential to detect this 'signature' turbine noise as a means to aid in identifying the presence of wind turbine noise within a measured signal.

It should be noted that newer models of wind turbines can now operate at variable rotor frequencies. Although the possible range of variation is relatively small, this could make it more difficult to detect these types of turbines via blade pass frequency, since the blade pass frequency will not necessarily hold constant over time.

2.2. Methods

Although the objective is always to discern whether turbine blade pass noise is present in a signal, multiple signal analysis methods can likely demonstrate this. The following methods have been selected for evaluation.

2.2.1. Fast Fourier Transform (FFT)

The FFT of a signal gives a representation of the signal in the frequency domain. In this way, spectral information such as blade pass harmonics may become visible as a series of evenly spaced spikes in amplitude. Since wind turbine blade pass harmonics are expected at very low frequencies, care must be taken in the FFT analysis, and an appropriately long sample time must be used to ensure a high frequency resolution of approximately 0.25 Hz. If frequency resolution is too low, the individual harmonic frequencies may not be distinguishable.

If wind turbine blade pass harmonics are detectable in the signal, it is expected that they should present themselves in an FFT as a series of amplitude spikes about 0.9Hz apart, in the range of 1 - 10 Hz.

2.2.2. Autocorrelation

An autocorrelation of a signal is a representation of the signal's similarity with itself as compared between different points in time. It is a very useful tool for finding periodicity within a noisy signal, such as detecting the fundamental frequency of a series of harmonics. Since wind turbine blade pass harmonics are at very low frequency, as with the FFT, a sufficiently long sample time must be analysed in order to identify repetition within the signal at the expected time of approximately 1.1 seconds.

If wind turbine blade pass harmonics are detectable in the signal, it is expected that they should present themselves in an autocorrelation as elevated correlation coefficients in the 1.0 – 1.2 second range.

2.2.3. Cepstrum

The cepstrum of a signal is defined as; the inverse FFT; of the logarithm; of the magnitude; of the FFT of a signal. More simply, it has been described as the spectrum of a signal's spectrum. As such, a series of pulses or harmonics present in a signal will have a period in the spectrum equivalent to the fundamental harmonic. In this way, cepstrum analysis can be a useful tool in the identification of fundamental harmonics.

If wind turbine blade pass harmonics are detectable in the signal, it is expected that they should present themselves in a cepstrum as a spike in magnitude between a quefrency of 1.0 – 1.2 seconds.

2.3. Implementation

Aercoustics Engineering regularly conducts wind farm noise audits, and as such has a large database of wind farm noise measurements, collected at various locations throughout Canada and the USA. Some of these measurements were recorded with low frequency microphones, and contain valid frequency information down to approximately 1Hz. Signals from these data sets were processed in MATLAB as per each of the described signal analysis methods. The results of each analysis were evaluated to determine the effectiveness of each method at identifying the presence of wind turbine blade pass noise.

3. Preliminary Results

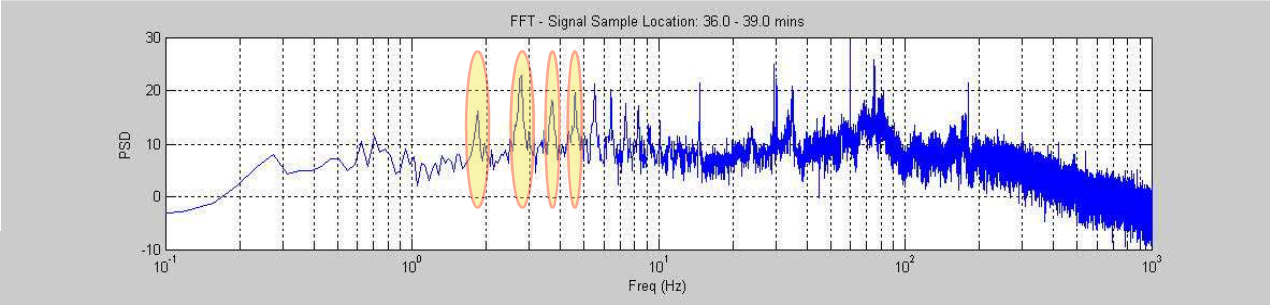
As suggested might be the case in section 2.1, evidence of wind turbine blade pass harmonics was not detectable in every analysed signal. In some signals, even though an operating turbine was measured nearby, none of the three methods were able to identify the blade pass noise. However, some of the measurement samples did exhibit evidence of the expected blade pass harmonics, detectable by all three methods. This implies that identifying blade pass noise within a signal also suggests the presence of wind turbine noise within that signal. The absence of detectable blade pass noise, however, does not necessarily preclude the existence of wind turbine noise within the signal.

For the purposes of this paper and a proof of concept of the discussed signal analysis methods, only measurement samples which displayed a strong component of the wind turbine blade pass harmonics were used for the following evaluations.

3.1. Fast Fourier Transform (FFT)

As expected, a fast Fourier transform can indicate the presence of wind turbine noise through revealing the increased spectral components at the turbine blade pass harmonics. It is important to note that these harmonics should be found between 1 – 10 Hz for a typical megawatt class turbine, exhibiting a blade pass frequency near 1 Hz. As indicated in section 2.2.1, the adjacent harmonics are separated by about 0.9 Hz; the measured blade pass frequency of the turbine. This characteristic is shown in the FFT illustrated in Figure 1 below.

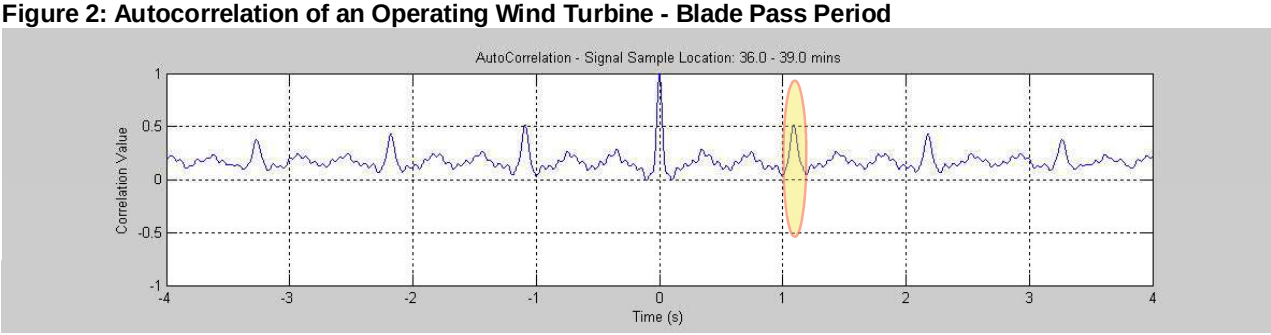
Figure 1: FFT of an Operating Wind Turbine – First Four Blade Pass Harmonics



3.2. Autocorrelation

Autocorrelation was perhaps the most successful method of identifying wind turbine blade pass noise, as it provided a higher degree of clarity in making the blade pass period more easily discernible. Since autocorrelation signals are in the time domain, the blade pass period can be seen in Figure 2 near 1.1 seconds, which corresponds to a blade pass frequency of approximately 0.9 Hz. Another advantage of detecting the blade pass noise with autocorrelations is that the location and amplitude of only one peak needs to be identified. This could simplify the determination of an objective criterion for this method of analysis, designed to indicate the presence of blade pass noise.

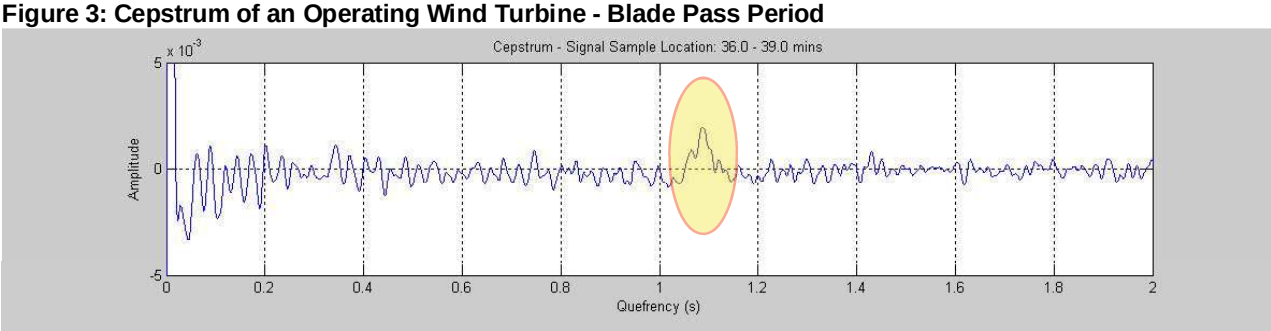
Figure 2: Autocorrelation of an Operating Wind Turbine - Blade Pass Period



3.3. Cepstrum

Lastly, cepstrum analysis also proved capable of identifying the presence of wind turbine blade pass noise within a measured signal. As with the autocorrelation, the cepstrum is in the time domain, and the blade pass period can be identified near 1.1 seconds in Figure 3. It was observed that the wind turbine blade pass period was not always as clearly identifiable as it was in the autocorrelation. Cepstrum analysis does, however, also have the advantage that the location and amplitude of only one peak would need to be identified to determine whether blade pass noise is present.

Figure 3: Cepstrum of an Operating Wind Turbine - Blade Pass Period



4. Next Steps

As this was only a feasibility study to determine the potential for incorporating a method of wind turbine detection in acoustic audits, there are many avenues of this topic yet to be explored.

A statistical study could be conducted to determine the reliability of the above discussed methods. Such a study should incorporate a variety of measurement data sets which include information on the locations and operational states of nearby wind turbines. The data should be analysed with the subject methods, and different 'criteria values' meant to indicate positive wind turbine noise detection should be tested. The rate of false positives and false negatives for each method should be quantified, and the optimal 'criteria value' for detection determined. This will help identify the likelihood that any of the signal analysis methods could successfully indicate the presence of a turbine. With this information, it may be possible to incorporate these methods into a wind turbine noise audit procedure, in the hope of improving the confidence and quality of the measured data set.

Another avenue for further study would be the assessment of additional signal analysis methods, and their potential for detecting wind turbine noise within a signal. Wavelet analysis, for example, may hold potential not only for identifying the blade pass harmonics within a signal, but also detection of wind turbine amplitude modulation within a signal.

5. Conclusions

A feasibility study of several signal analysis methods was conducted to determine the ability of each method to detect wind turbine noise within a measurement signal. Fast Fourier transforms, autocorrelations, and cepstrum analysis were all evaluated for their potential to identify blade passage noise resulting from the operation of wind turbine generators. All three methods were shown as capable of detecting the presence of blade pass noise, and thus the wind turbine, in some of the analysed measurement signals. It was also observed that sometimes, even with an operating turbine nearby, all three methods were unable to identify the turbine blade pass noise. Some strategies for conditioning of the measurement signal were discovered, which could improve the likelihood of successfully detecting the blade pass noise. To determine the average success rate exhibited by each of the reviewed methods, and the potential benefits these methods could bring to wind turbine noise audit procedures, further study and statistical analysis are still required.