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ELIMINATING WIND NOISE CONTAMINATION OF WIND TURBINE NOISE AMPLITUDE MODULATION RATINGS – FIRST VALIDATION

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Microphone wind noise can corrupt outdoor measurements and recordings. It is a particular problem for wind turbine measurements because these cannot be carried out when the wind speed is low. Previous studies simulated the effect that microphone wind noise has on the accuracy of a proposed Amplitude Modulation (AM) metric and found that even relatively low wind speeds of 2.5 m/s errors of over 4 dBA can result. It has also been shown that a wind noise detection algorithm can automatically find uncorrupted sections of the recording, and so recover the true AM metrics. This paper shows first results on validating the simulation approach by applying the automatic detection to recordings from pairs of microphones mounted on an acoustic camera array in combination with the results from the AM rating method suggested by the Institute of Acoustics Amplitude Modulation Working Group.

Keywords: Wind turbine noise, amplitude modulation

1. Introduction

Wind turbine noise has long been thought to be more annoying than other types of environmental noise [1] potentially because of its amplitude modulated (AM) character. Yet when measured at surrounding resident's dwellings, the amount of AM is difficult to establish for various reasons yet there is economic pressure for an international standard on quantifying AM [2]. In an attempt to develop a reliable measurement method for AM noise the Institute of Acoustics founded the Amplitude Modulation Working Group (AMWG) who after extensive consultation [3] proposed an AM rating method [4]. The metric analyses 100ms Laeq data both in frequency and time domain to rate the AM modulation depth. By using band-filtered data and accumulating the results over 10 minutes the method is supposed to reject ambient noise and give reliable AM ratings. First results from the method [5] seem to support this claim although it is curious that in high wind conditions high AM modulation depths have not been measured.

Some simulation work has raised questions about the reliability of the method where the recording microphones are exposed to considerable wind even where they are equipped with common windshields [6, 7, 8]. The results suggest that the rating values would be affected by wind noise from wind speeds as low as 2.5 m/s. It was also found that a significant proportion of data containing AM would not result in valid AM ratings by the proposed algorithm when wind noise is present.

Wind noise in recordings can be detected by signal processing and therefore rating effects can potentially be mitigated.

The obvious criticism of these results is that they are purely based on simulations of synthesised stimuli. Therefore, the current work applies both the rating method and the wind detection algorithm to acoustic camera recordings of wind turbine sound to understand the prevalence of wind noise in real recordings and make qualitative comparisons with the AM ratings.

2. Experimental design

At the DTU wind energy test site in Roskilde, Denmark two models of Acoustic Camera arrays recorded the sound received at a distance of 50 m from an operational wind turbine. The other turbines were switched off. A nearby road added some intermittent traffic noise and some talking can be heard in the recordings.

2.1 Acoustic Camera

Wind turbine sound was recorded with a star-shaped 48-microphone Acoustic Camera of diameter 3.4 m (a Star48), and a 120-microphone spiral array of diameter 4 m (a FlexStar120). The Acoustic Cameras were placed on the ground 48.5 m downwind of the turbine along the turbine axis direction, as shown in Fig. 1. Measurements were also conducted upwind of the turbine at hub height using the Star48 from an elevated platform. The microphones used for the current study are shown in the yellow rings in Fig. 1.

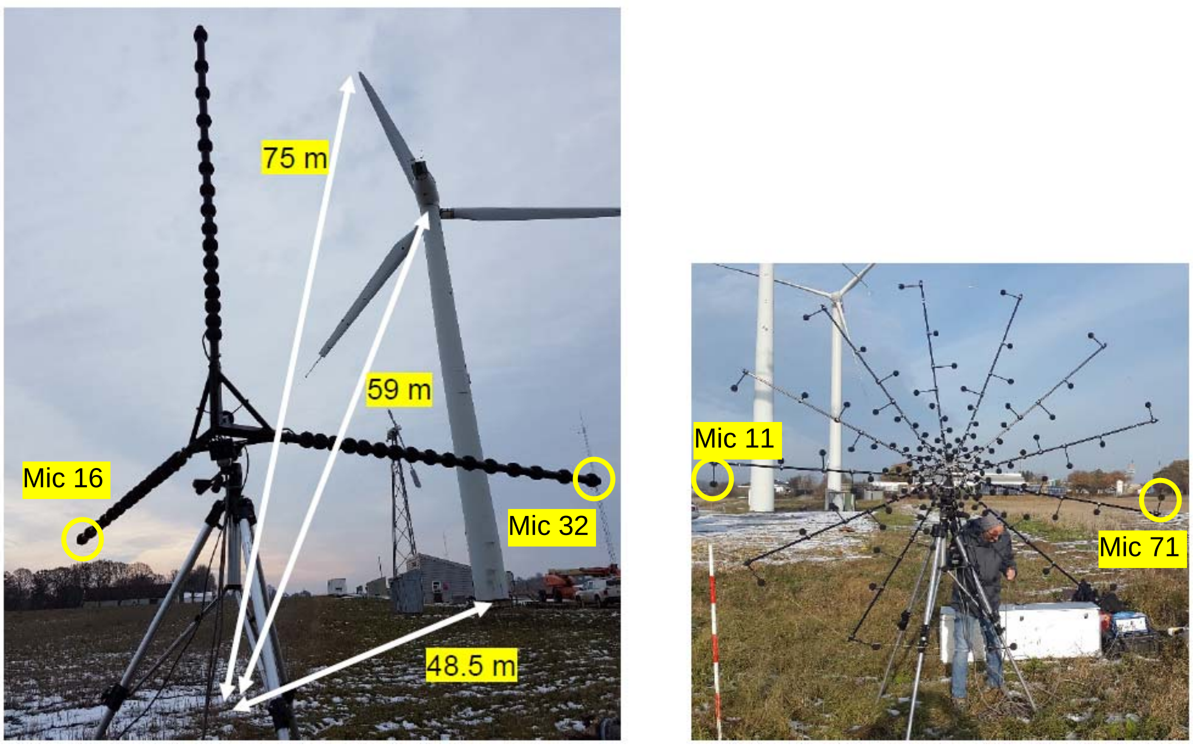


Figure 1. The turbine and Star48 array (left), and the FlexStar120 (right) (adapted from [9]).

2.2 Turbine Operation

The acoustic cameras were placed close to the Nordtank NTK 500/41 turbine in the position shown in Fig. 1. To get AM ratings in different modes of turbine operation sound was recorded at maximum rotation speed, during start up and slow down at the ground. At hub height constant turbine rotation and start up were recorded.

3. Method

As a first step to compare AM ratings from recordings contaminated with wind noise with uncontaminated ones the current work applies both the AM rating method and the wind detection algorithm to acoustic camera recordings of wind turbine sound.

3.1 AM ratings

The input into the AM rating method needs to be in the form of 100 ms Laeq bandpass filtered data. Three frequency bands are suggested by the AMWG: 50-200 Hz, 100-400 Hz and 200-800 Hz. Therefore the recordings available at a sampling rate of 129 kHz were converted to these formats. They were then used as input to the Python code developed and provided by the AMWG [10] to find the AM ratings. For every 10 second period AM ratings are calculated in dB together with the modulation frequency and the peak prominence. This information allows judgment on data quality for example when the detected fundamental modulation frequency is either variable or clearly not the one of the wind turbine blade passing frequency. Where data are available for periods longer than 10 minutes the method then goes on to use the data from the frequency band providing the highest ratings to accumulate the values for a final 10 minute rating if more than 50% of the ratings were valid.

3.2 Wind detection in sound recordings

The recordings were then used to detect the level of wind noise using an algorithm proposed and tested by Jackson *et al.* [11]. For every 23 ms frame the wind noise level is classified according to the following wind noise levels.

(a) ClassL = 0: LAeq < 30 dB (no wind);
(b) ClassL = 1: 30 < LAeq <= 50 dB (low wind);
(c) ClassL = 2: 50 < LAeq <=70 dB (moderate wind);
(d) ClassL = 3: LAeq > 70 dB (high wind)

Over 1s these class values are averaged, this forms one of the main outputs of the wind noise detection algorithm. To identify where microphone wind noise could be a problem a simple threshold is applied on the average wind noise level class of 0.5. This corresponds to an A-weighted level of around 30 dBA. (as this is the lowest class there is not a direct mapping between the numeric class and a dBA level.

The wind rating allows a judgement whether there will be sufficient wind noise in typical recordings of wind turbine sounds to make a correction of the rating methods necessary.

4. Results

Five recordings from 2 different microphones each were available for analysis. The first two were taken on a platform at turbine hub height and involved the turbine rotating at full operational speed and with the turbine starting up. The latter three recordings were from ground based measurements with continuous turbine operation, the turbine starting and stopping, respectively. The start-up periods contain only short periods of AM and were therefore not rated.

4.1 AM ratings

Table 2 shows the different ratings for the three remaining periods for each of the two microphones. For each microphone the rating are provided for the three types of band limited data in the frequency bands 50-200 Hz, 100-400 Hz and 200-800 Hz. The 10 second wind level average as detected by the wind detection method is also shown. The wind level has been normalised to values between 0 and 1. Where cells are empty a valid rating was not found. Grey shading indicates AM ratings at a modulation frequency that is likely to be the first harmonic of the blade passing frequency.

Table 1. Amplitude modulation ratings in 10s intervals for different recording locations, turbine operating modes, different frequency filters of recording. The relative wind levels have been established from the microphone recordings. Grey shading indicates a rating for a fundamental frequency that is higher than the turbine modulation frequency. Blank cells indicate that no valid AM rating has been made.

	Microphone No 32				Microphone No 16			
	wind level	50-200	100-400	200-800	wind level	50-200	100-400	200-800
Elevated, rotation	0.224			1.61	0.202			1.86
Ground, rotation	0.092		7.4		0.055		6.19	
	0.15			4.67	0.072	2.44	3.21	3.15
			5.12	3.03		2.47	3.28	3.08
Ground, stopping	0.115	6.9	4.72	3.58	0.112	2.93	2.96	3.57
	0.131	5.38	2.56	3.08	0.078	2.41	3.43	2.88
	0.101				0.079			2.64
	0.08				0.093	2.18		
	0.08	8.96			0.06			1.28
	0.047				0.012			

The table shows that 27 out of 60 periods return values with sufficient peak prominence in the frequency domain to result in valid AM ratings. For the elevated array with constant turbine rotation the only valid ratings occur for data in the frequency band 200-800 Hz which might be due to the dominant low frequency content in the wind noise.

With the array on the ground considerable more valid AM ratings were observed from Mic 16 than from Mic 32 during constant turbine rotation.

The longest recording in that group was when the turbine was slowed down and brought to a halt. The first two 10 second periods show valid AM ratings from both microphones in all three frequency bands. In the following 10 second interval the turbine starts to slow down as shown in [9].

4.2 Wind noise detection

The corresponding 10 second normalised wind levels are shown in Figs. 1 and 2. Fig. 1 contains the periods corresponding to the Table 1 values whereas Fig. 2 shows the wind noise ratings during the turbine start-up periods. It is evident that all periods contain wind noise. The elevated measurement shows the majority of wind ratings between 0.1 and 0.4 whereas the ground measurements result wind levels between 0 and 0.3. In accordance with expectation these values are on average lower due to the vertical wind shear. It is notable that Mic 16 values in Fig. 2b) are consistently lower than Mic 32 values. This coincides with the higher number of valid AM ratings for Mic 16. Generally it is interesting to note that the correlation between to microphones spaced less than 4 m apart is not very high. The correlation coefficients do not exceed 0.5 even for the longer periods.

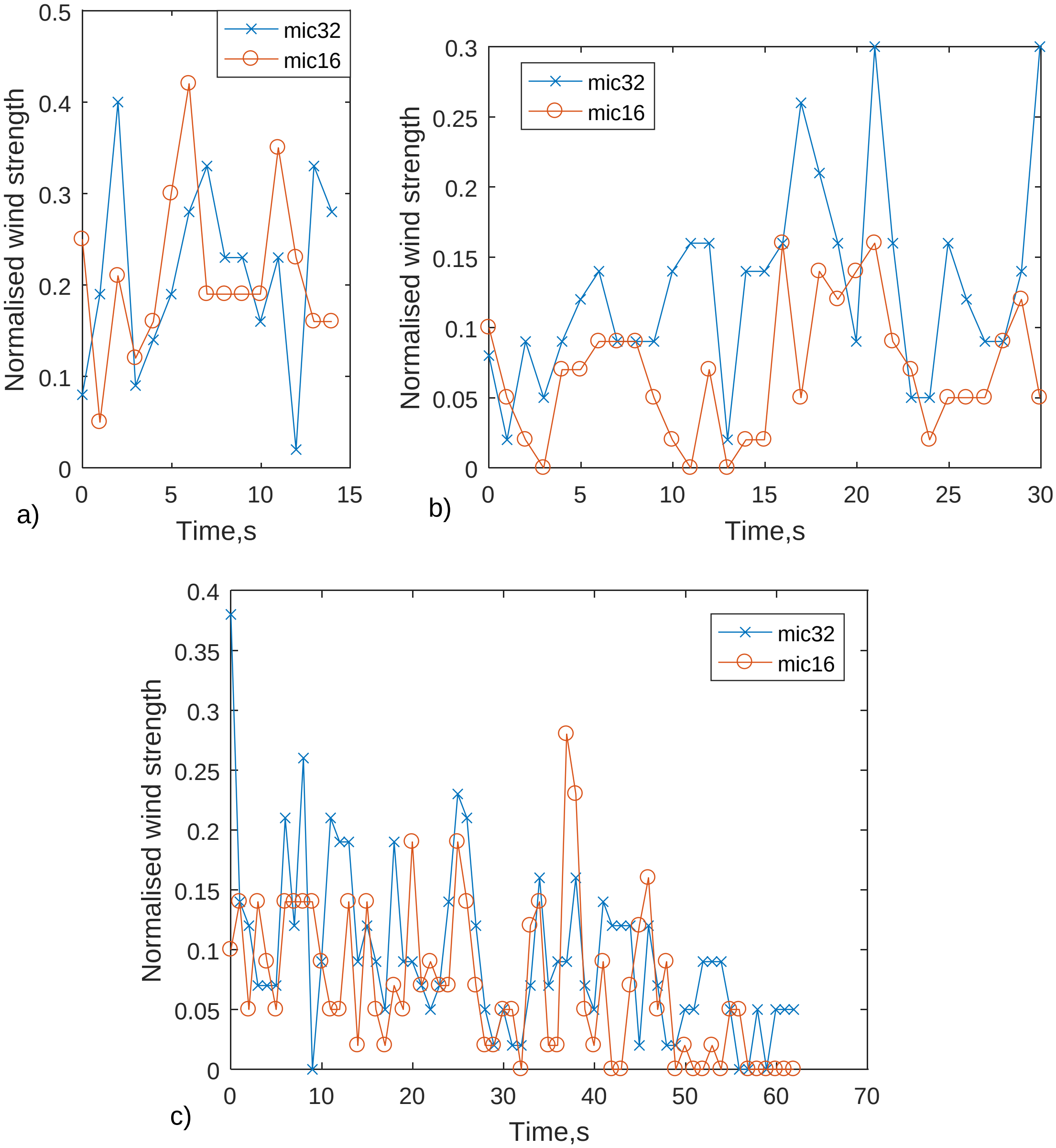
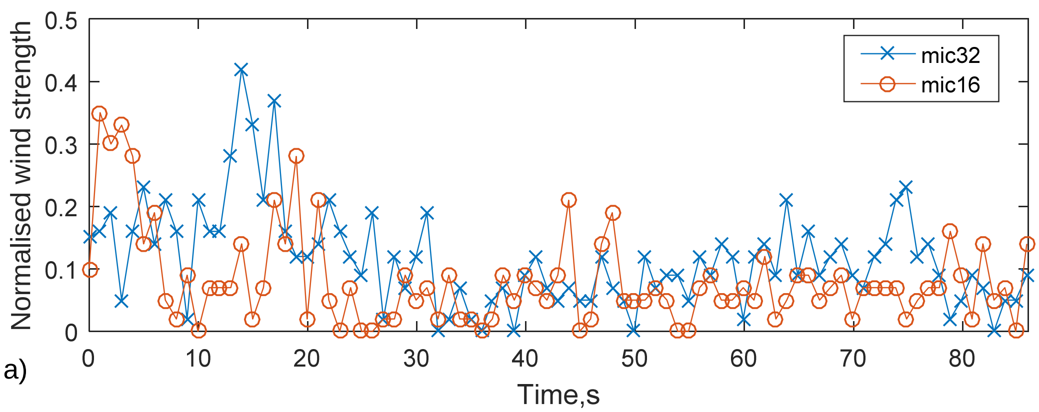


Figure 2: Wind noise strength detected in recordings normalised between 0 and 1 and averaged for 1 second. a) elevated position with continuously rotating turbine, b) ground position with rotation and c) ground position with the turbine being stopped during the recording.



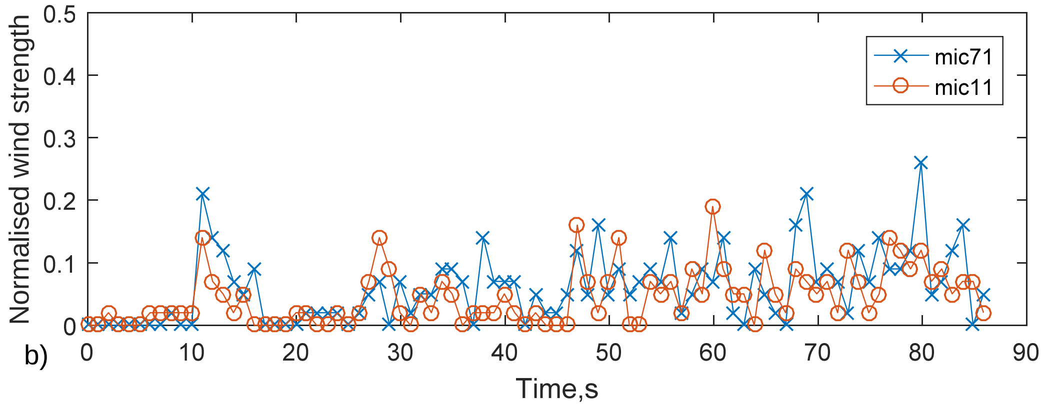


Figure 3: Wind noise strength detected in recordings normalised between 0 and 1 and averaged for 1 second during the turbine start-up periods. a) Elevated position b) ground position.

5. Conclusions and further work

In analysing wind turbine recordings both for their AM ratings and their wind noise content a first step has been made to potentially improve AM ratings. Due to the shortness of the available recordings no general conclusions can be drawn and the results have to remain rather qualitative in nature. There is some evidence of continuous wind noise in the recordings and that AM ratings might be affected by wind noise. In further work we will use longer recordings to show these effects statistically. The wind detection also needs to be validated by co-located high resolution meteorological data.

Furthermore, a suitable algorithm and thresholds need to be established to remove the periods most heavily affected by wind noise to come up with more reproducible AM ratings. Thus, it will be possible to avoid the potential criticism AM might be underreported because of reduced data availability due to wind noise.

One big remaining unknown is how human perception of AM in the presence of wind noise compares to the microphone recordings. Two scenarios are possible: AM gets masked by wind noise in the ear in a very similar way to the way microphone recordings are affected. In this case it would be wrong to remove wind noise from the recording as that process would artificially enhance the AM that is in reality not perceived to that extend. The second scenario is that because of the stereo nature of the ears they are differently affected by wind noise in that location and identification of AM is much more developed than in standard acoustic environmental recording equipment. Further work is required to clarify which scenario is more realistic. It is also important to point out that listeners indoor will be differently affected by wind noise than outdoors listeners.

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