Characterisation of noise in homes affected by wind turbine noise

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ABSTRACT

A growing need for low carbon energy production necessitates the use of renewable resources such as wind power. However, residents living near wind farms often state that annoyance due to wind farm noise is a serious problem that affects their wellbeing. This paper describes a new methodology for recording noise and annoyance within residents' homes affected by wind turbine noise. The technique records time-series noise measurements allowing complete analysis of the signal using a variety of post processing techniques. Preliminary results from the system in a single home near a wind farm are presented including overall sound pressure level with A, C and Z weighting, narrow band frequency spectrum and amplitude modulation depth correlated with resident rated annoyance level. This information provides insight into the nature of noise in homes close to wind farms.

INTRODUCTION

Traditional means of measuring noise in residents' homes affected by wind turbine noise may not have the required fidelity to capture important features of noise character. Features such as amplitude modulation and low frequency noise are not able to be resolved from standard techniques that rely upon 10-minute averages and A-weighting. However, it is difficult to record noise in sufficient detail in the field to resolve these effects due to large data storage and post-processing requirements. Annoyance events may be hard to predict and only occur once per day, or occur when certain weather conditions are present. Continuous recordings in these situations are sometimes impractical and a different methodology is needed. To overcome these issues, a new resident-controlled noise and annoyance measurement system has been devised and is presented in this paper.

Only a few field studies have investigated the relationship between wind turbine noise and annoyance in the past (Wolsink et al., 1993, Wolsink and Sprengers, 1993, Pedersen and Persson Waye, 2004, 2007, Pedersen et al., 2009, Bockstael et al., 2011) and all of these studies use A-weighted sound pressure level as the sound emission metric to correlate with annoyance. Pedersen and Persson Waye (2004) found that wind turbine noise is considered more annoying than other community noise sources (aircraft, road traffic and railway noise) at comparable noise levels. This was attributed to the intrusive characteristics of wind farm noise such as temporal variability and night time audibility. Annoyance was also found to be strongly correlated with a negative attitude toward wind farms and their visual impact on the environment. Additionally, the risk of annoyance was observed to increase with enhanced turbine visibility (Petersen et al., 2009). Bockstael et al. (2011) also examined the relationship between operational variables and wind turbine noise annoyance. They found that the risk of high annoyance is dependent on angular blade velocity and wind direction.

Those annoyed by wind turbine noise commonly describe the sound as 'swishing', 'pulsating', 'thumping' or 'throbbing' (Pedersen and Persson Waye, 2004, Siponen, 2011). These descriptors are related to the spectral and temporal properties of noise suggesting that sound frequency content and fluctuation should also be examined in conjunction with the overall sound pressure level to determine the relationship between wind turbine noise and annoyance. The aim of this paper is to describe a new methodology to record noise and annoyance in residents' home affected by wind turbine or other forms of environmental noise that are not easily characterised or analysed by traditional means. The technique records time-series recordings that allow complete analysis of the signal using a variety of post processing techniques. Preliminary results from a trial of the system in a home near a wind farm are presented and show the type of data that is obtained and the different ways it can be analysed.

METHODOLOGY

The system was designed to be placed in a resident's home and operated by them when they noticed environmental noise. Importantly, the resident rates the annoyance level of the noise using a ten-point scale, where 1 represents not-annoyed and 10 represents the highest level of annoyance. This annoyance scale is subjective and ad-hoc and also assumes that the resident has experienced a full range of environmental noise levels over a period of time and can perceive differences between each. The resident is also able to provide comments describing the character of the noise source or any other information of interest (e.g. weather conditions).

It is important to note that the system in its present form has no link with the wind farm operational state. The system simply asks the resident to record, rate and comment upon noise that they perceive to be attributed to the wind farm. It is hoped that wind farm operational data can be obtained in the future to correlate power production, wind conditions and rotor motion with residents' noise measurements.

The system uses a Brüel & Kjær 4958 20 kHz precision array microphone connected to a 4mA constant current microphone signal conditioner. This microphone has a flat frequency response over the 10 Hz–20 kHz frequency range and was held approximately 1.5 m from the floor with a large wind sock placed on it. The output of the microphone and signal conditioner was amplified using a Krohn-Hite Model 3362 Dual Channel Filter before recording the signal using a Lab-

Jack U3-HV 12 bit data acquisition device. The system records 10 seconds of time-series signal at a rate of 12 kHz onto the hard drive of a laptop computer connected to the data acquisition device. The microphone was placed in a separate room to the other components of the system. Figure 1 shows photographs of the system.

(a) Microphone and wind sock on stand.

(b) Data acquisition device, amplifier and laptop computer.

Figure 1. Photographs of the system setup.

The software was programmed in the Visual Basic 6 language. An easy interface between the resident and the data logging system was required so that the system is as user friendly as possible for people who were unfamiliar with computers. Figure 2 shows the software graphical user interface.

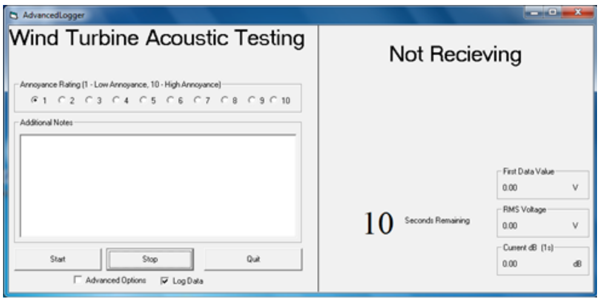

Figure 2. Software graphical user interface.

RESULTS

The system was placed in a resident's home that was situated approximately 2.5 km west of an operational wind farm in South Australia. The microphone and wind sock were placed in a room with a partially open window while the other components of the system were placed in a neighbouring room. The results shown in this paper were taken during the period 22/4/2012 to 8/5/2012. A total of 53 recordings were derived from the test and will be used to illustrate the capabilities of the system and to provide a preliminary characterisation of the noise that this particular resident found annoying and attributed to the wind farm.

Table 1 provides a summary of the results obtained during the test period. It has a column describing the annoyance rating or location of the system, averaged levels for various weightings, the number of samples collected at each annoyance rating and the standard deviation of the results when the number of samples is seven or greater. The final column states selected descriptive comments provided by the resident just before they recorded the noise. The most descriptive and representative comments were selected from the recordings.

Table 1 also states the overall sound level (for various weightings) measured from a line of 6 operative turbines (referred to as 'Wind turbine noise'). This measurement was recorded on a November afternoon in 2011 broadside to the wind farm at a distance of approximately 800 m (Doolan et al., 2012). Additionally, Table 1 states the overall sound level of the equipment noise floor measured in the anechoic chamber at the University of Adelaide (referred to as 'Noise floor'). The table shows that for all Annoyance ratings, the overall sound levels measured in the resident's home are significantly below that measured close to the line of wind turbines and above that of the noise floor.

The number of samples measured in the resident's home are small, therefore any conclusions are limited to this data set and cannot be made general to wider wind farm noise or residents' perception of it. The data does give interesting insights into the character of noise that a rural resident perceives as annoying and the operation of the noise recording system itself.

The levels of noise measured in the resident's home are low, but show a small but significant increase with Annoyance rating. Figure 3 plots the mean overall sound levels using three different weightings (Z, C and A) against Annoyance rating over the frequency range of 10-1000 Hz. The Z (unweighted) and C weighted data show an overall increase with Annoyance rating while the A weighted data do not. This is because the majority of the acoustic energy is contained in the lower frequencies. This can be illustrated by examining Figure 4, which shows the single sided power spectral density versus frequency of recordings at various Annoyance ratings. The figure shows that as Annoyance increases, energy levels increase in the 10-30 Hz band as well as increasing levels of broadband energy to 1000 Hz, the most of which occurs at an Annoyance rating of 8. Note that the peaks at 50 Hz and its harmonics are due to electrical interference and should be ignored.

Table 1. Summary of results.

Annoyance/Location	dB(Z)	dB(A)	dB(Z) 10-30 Hz	Number of samples	Standard deviation	Selected Comments
1	50.6	31.4	49.8	2	-	Hardly turning
2	53.7	32.6	53.0	11	4.4	Quiet hum/murmur from turbine
3	52.6	31.3	51.8	7	3.3	Faint rumbling can be heard
4	54.7	32.2	54.3	11	3.3	Thumping/rumbling noise
5	57.1	32.5	56.6	11	5.9	Rumbling
6	53.8	31.3	53.4	7	2.7	Turbines moving quite fast, not as much wind by house
7	54.3	31.2	54.0	2	-	Can feel pounding
8	66.6	34.0	66.4	1	-	Loud thumping/rumbling
9	56.1	31.0	55.9	1	-	Roaring, rumbling noise
Wind turbine noise	75.7	46.9	75.0	1	-	~800 m from wind farm
Noise floor	39.3	29.6	36.3	1	-	

The selected descriptive comments provided in Table 1 show that the resident is able to perceive unwanted noise and describe it. The comments suggest that the noise is perceived as thumping, rumbling, pounding and roaring. Such descriptions are consistent with the spectra in Figure 4. Thumping or pounding may be associated with the broad peak between 10-30 Hz while the rumpling and roaring may be associated with the broadband energy to 1000 Hz as well as the spectral balance. It is possible that acoustic energy below 10 Hz may be responsible for thumping noise; however, future measurements with new microphones capable of measuring below 1 Hz will be performed to help resolve this issue.

The overall levels are low and are at the limits of detectability. For example, the ISO:226 (2003) hearing threshold at 20 Hz is approximately 70 dB and at 100 Hz is 25 dB. At such low levels, individual differences in hearing sensitivity will make large differences in the rating of Annoyance. A recent review by Leventhall (2004) examines the link between low frequency noise and annoyance. The major conclusions from the review are that annoyance by low frequency noise is individual due to a combination of personal and social moderating influences. Personal sensitivity to low frequency noise can be influenced by age, gender and social context as well as the ability to cope with an external background stressor, such as noise. Further, Leventhall (2004) suggests that there is a possibility of a “learned aversion” to low frequency noise so that a person may be able to develop an enhanced perceptibility to low frequency noise by focussing on it over long periods of time. Thus the sensitivity of a person to low frequency noise is highly individualistic and relates not only to the noise levels but the context of the person’s life that affects the personal and social moderators that influence their sensitivity and reaction.

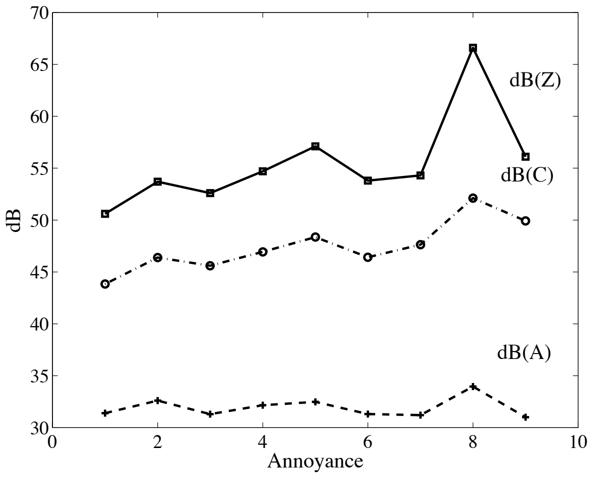

Figure 3. Mean dB measurements versus Annoyance rating by resident. The levels were calculated over the 10-1000 Hz frequency range.

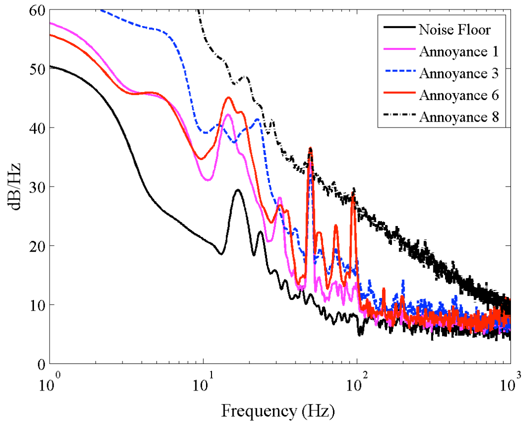

Figure 4. Power spectral density (unweighted) of the acoustic data for various resident-rated annoyance levels.

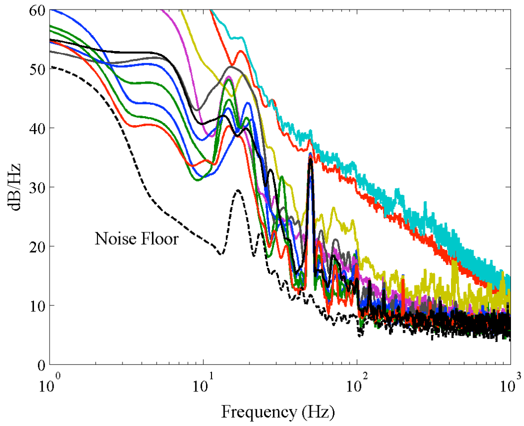

Figure 5. All power spectral density results (unweighted) for acoustic signals rated with Annoyance = 5 by the resident. Also shown is the noise floor of the system as a dashed black line.

The subjective nature of an individual's Annoyance rating is illustrated in Figure 5. Here, all single-sided power spectral density results collected for an Annoyance rating of 5 are presented, as well as the noise floor of the system. Most spectra have the same shape, showing a broad peak over the 10-30 Hz range and some broadband energy below 1000 Hz. However, some results show higher levels again and are entirely broadband in nature. Thus, the rating of annoyance may be influenced by the particular time of day or personal situation the resident finds himself or herself in. For example, the annoyance to a low level noise may be higher at night than in the day, due to the masking effects of background noise or the personal judgement that it can be nosier in the daytime. Alternatively, if the resident is stressed by other personal or social factors, a lower level noise may be rated as more annoying than at a time when these factors are not present.

Another factor that may influence a person's sensitivity to low frequency noise is level variation or amplitude modulation (Leventhall, 2004). Figure 6 shows the 125 ms time averaged unweighted sound pressure data for two resident-rated Annoyance levels. The mean level is different for each Annoyance, however, there is significant amplitude modulation in each signal.

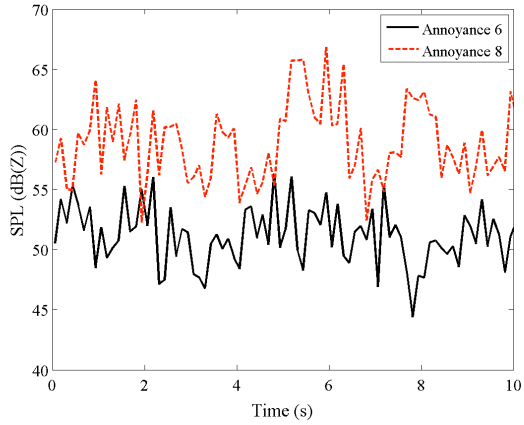

Figure 6. 125 ms time averaged (FAST) unweighted time series sound pressure data for two resident-rated Annoyance levels. The data were band-passed over 10-1000 Hz.

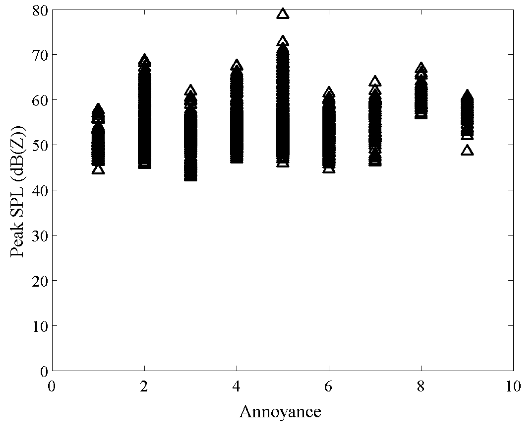

Figure 7. Peak SPL (dB(Z)) from each 125 ms time averaged time series.

To further investigate the link between level variation and annoyance, a peak detection algorithm was used to extract each peak from each 125 ms time averaged data record. These peaks are plotted against Annoyance rating in Figure 7. There is considerable scatter in the data and no trend can be discerned.

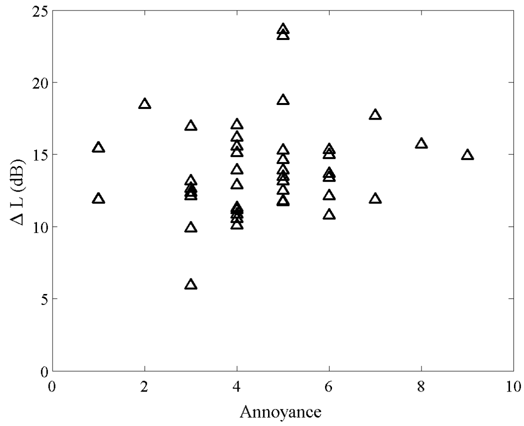

Figure 8. Amplitude modulation depth versus resident rated Annoyance level.

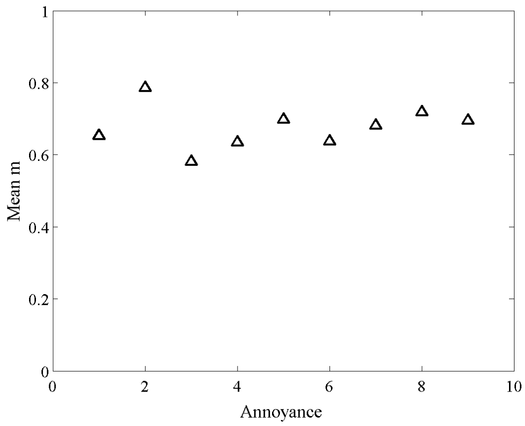

Figure 9. Mean values of the degree of modulation (m) versus resident rated Annoyance level.

The depth of amplitude modulation, defined here as the difference in dB between the maximum and minimum levels in each 125 ms time-averaged data record (ΔL), is plotted against Annoyance rating in Figure 8. While there is much scatter, there is no trend with Annoyance. Further, the degree of modulation (m) can be used to characterise amplitude modulation depth (Fastl and Zwicker, 2007). The degree of modulation is defined by

$$\Delta L = 20\log_{10}\left[(1+m)/(1-m)\right] \qquad (1)$$

Figure 9 plots the mean value of m for each Annoyance rating. This result, and those in Figures 7 and 8, show that there are significant levels of amplitude modulation in the recorded signals, but the degree of modulation is relatively uniform for each Annoyance rating and no trend with annoyance can be found. While an interesting result, further studies are required to determine whether the presence of amplitude modulation is needed to make this type of low frequency noise more perceptible or annoying, or if it is the solely a function of overall level.

SUMMARY AND CONCLUSION

This paper has described a new methodology for recording noise and annoyance within residents' homes affected by wind turbine noise. The technique records time-series recordings that allows complete analysis of the signal using a variety of post processing techniques. While being used to characterise wind turbine noise in this study, the system can be used to record noise and annoyance in residents' homes affected by other forms of environmental noise.

Measurements taken in a single resident's home near a wind farm show an increase in the overall mean Z (unweighted) and C weighted sound level with Annoyance rating. No increase was, however, observed in the mean A weighted sound level and this is due to the majority of the acoustic energy being contained in the lower frequencies. In particular, the energy levels within the 10-30 Hz band were observed to increase with Annoyance rating. Additionally, significant amplitude modulation was detected in the noise signals; however, no trend with annoyance was observed.

It should be noted that the results presented in this paper are the preliminary results of a much larger study to investigate the character of wind turbine noise within homes. There is a need for a much more comprehensive data set measured in a large number of homes to draw more definite conclusions about the nature of noise in residences close to wind farms.

Future measurements with the system will incorporate use of a microphone capable of measuring below 1 Hz to capture noise over a larger frequency range than is reported in this study. Additionally, it is hoped that wind farm operational data can be obtained to correlate power production, wind condition and rotor motion with residents' noise measurements. Another improvement is the incorporation of a high-resolution data acquisition system that will eliminate the need for an amplifier. A weather station located near the home would also be beneficial to record local meteorological conditions that will help identify wind noise from foliage and building facades.

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