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Undertaking automated wind farm noise feature analysis directly on a live measurement system

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Challenges of wind farm noise

- Noise levels relatively low - often comparable to residual noise
- Measurements in windy conditions
- Variability of noise levels dependent on the changes in the weather conditions – *an essential output*
- Extended noise measurements often required
- Undertaken in rural locations - difficult or time-consuming to access

➢ The noise monitoring process ordinarily requires the deployment of a temporary logging system followed by regular site visits to manually download noise data;

➢ Downloaded noise data is then analysed against separately acquired operational/meteorological data from the wind farm;

➢ Increasing focus on *noise features*: analysis may be required for some periods, in response to complaints or for specific weather conditions identified;

➢ This requires *audio recordings* for subsequent acoustic feature analysis: manual download of data required due to size of the resulting data.

Evolving state of the art in monitoring

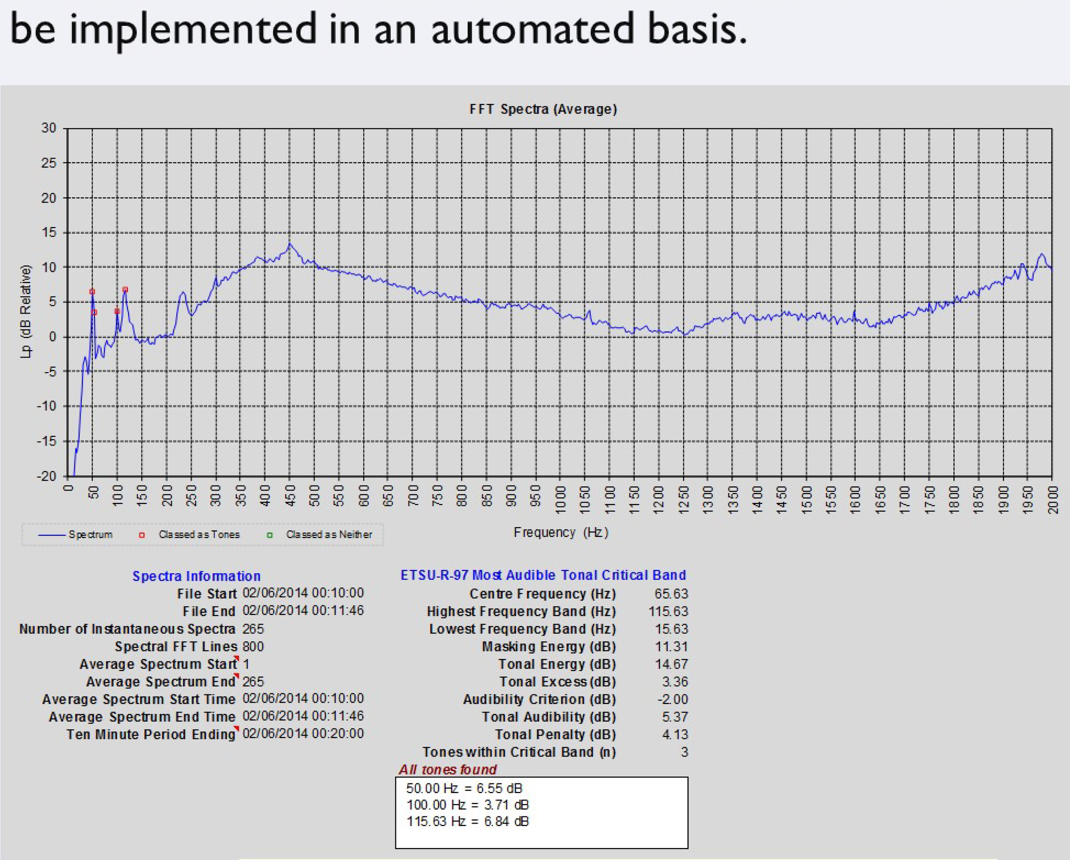
- Rapid evolution in noise measurement technology
  - Expanded processing capabilities
  - Wide range of measurement indices
  - Continuous frequency band data
  - Periodic or continuous audio recordings
- Enhanced communications (mobile & landline) available for remote communications
- These advances have allowed the development of "smart" noise meters, with advanced automated and autonomous noise measurement systems

Requirements: noise levels and features

In most European countries, local regulations impose limits on the **noise levels** experienced at residential receptors, in order to provide protection of amenity and limit risks of disturbance and complaints during operation of the wind turbines.

This mainly tends to comprise a limit on the noise level due to the turbines at the nearest residential properties. This can vary due to wind speed but also wind direction due to propagation effects.

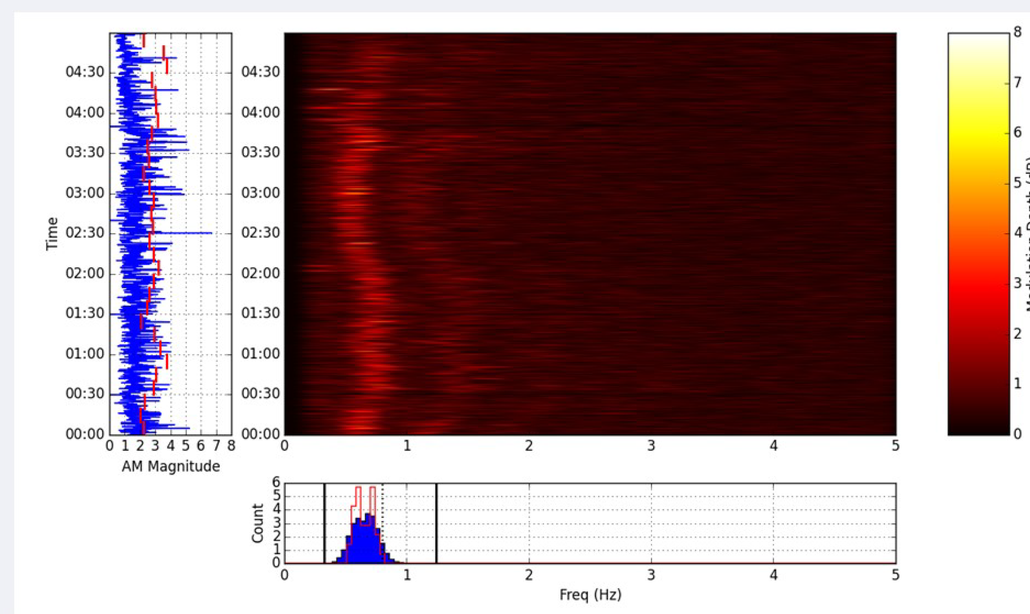
Several regulations also require the assessment of **tonality** in the wind farm noise. This is either measured at source in the IEC 61400-11 method or at receiver locations with methods in the ISO 1996-2 [1] standard or for example the ETSU-R-97 [2] method in the UK. These are based on Fourier analysis which can be implemented in an automated basis.



Result of an automated ETSU-R-97 tonal analysis process developed by the authors – ***tones are highlighted in red in the spectrum, with the tonal audibility and indicative penalty displayed.***

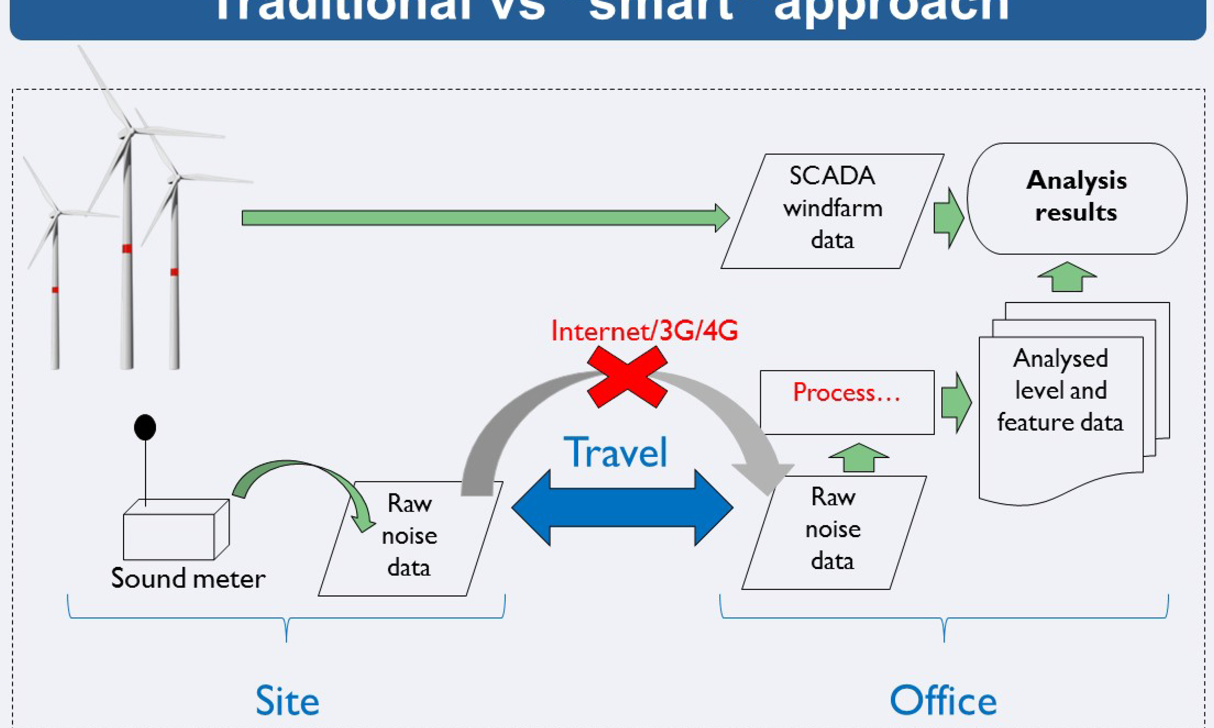
Amplitude modulation (**AM,** *i.e.* "swish" or "thump" noise) is a potential feature of wind turbine noise which has received increasing attention in the last 10 years. Analysis techniques are being developed [3][4] to evaluate the level of modulation in the noise. Such techniques are also based on Fourier analysis and can be automated in an implementation in the Python language for example.

Measuring AM as it varies with weather and operational conditions has allowed the study of mitigation measures developed for this feature of the noise, as reported at a previous EWEA conference [5].



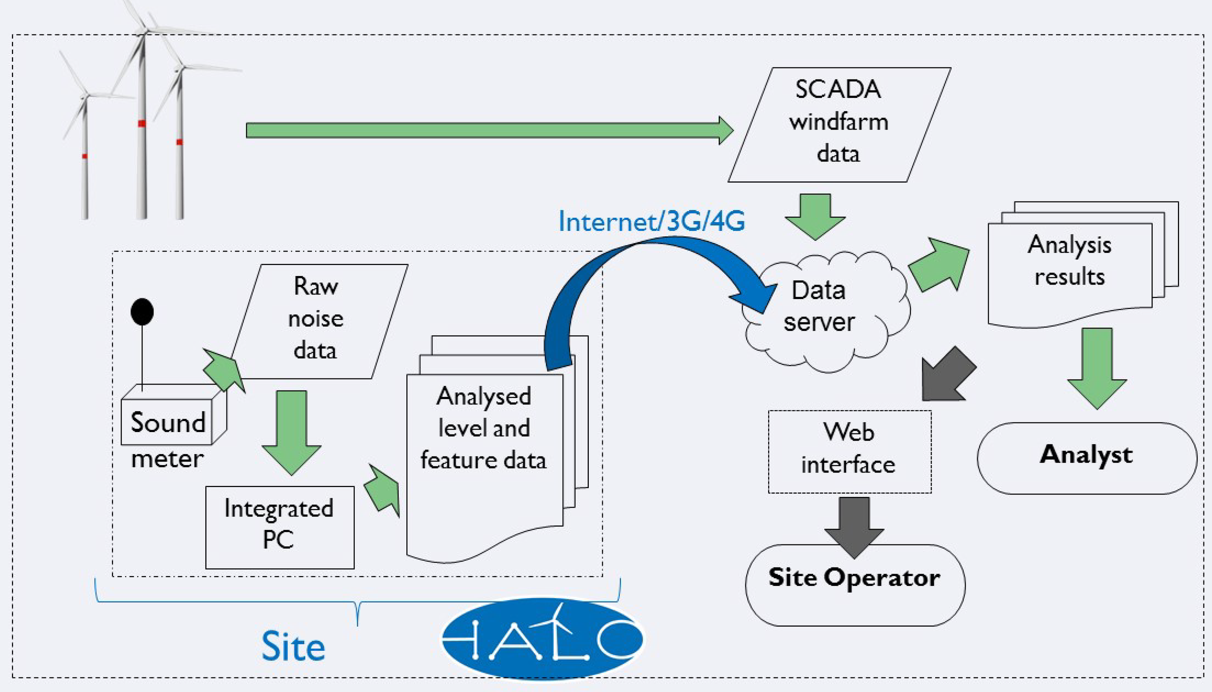
Result of an automated amplitude modulation analysis – ***this shows modulation at a rate depending on the rotational speed of the turbines***

Traditional vs "smart" approach



Standard site noise assessment approach

The diagram above shows a traditional noise measurement approach in which noise data (including audio files) are measured continuously, but only collected periodically during a site visit (with data transmission either not technically possible or limited due to the large file size). Processing is then undertaken in the office, undertaking the required analysis in relation to turbine operational parameters.



Smart meter approach with *in-situ* data processing

The diagram above shows a novel system in which the processing is undertaken directly by the on-site system, ("**in-situ processing**" architecture). producing a set of results including:

- Overall noise levels
- Tonality audibility and frequency (with spectra)
- Modulation frequency (if present) and magnitude

The resulting analysed data is relatively compact and results can be transmitted through the mobile phone data network to a centralised server for storage and analysis.

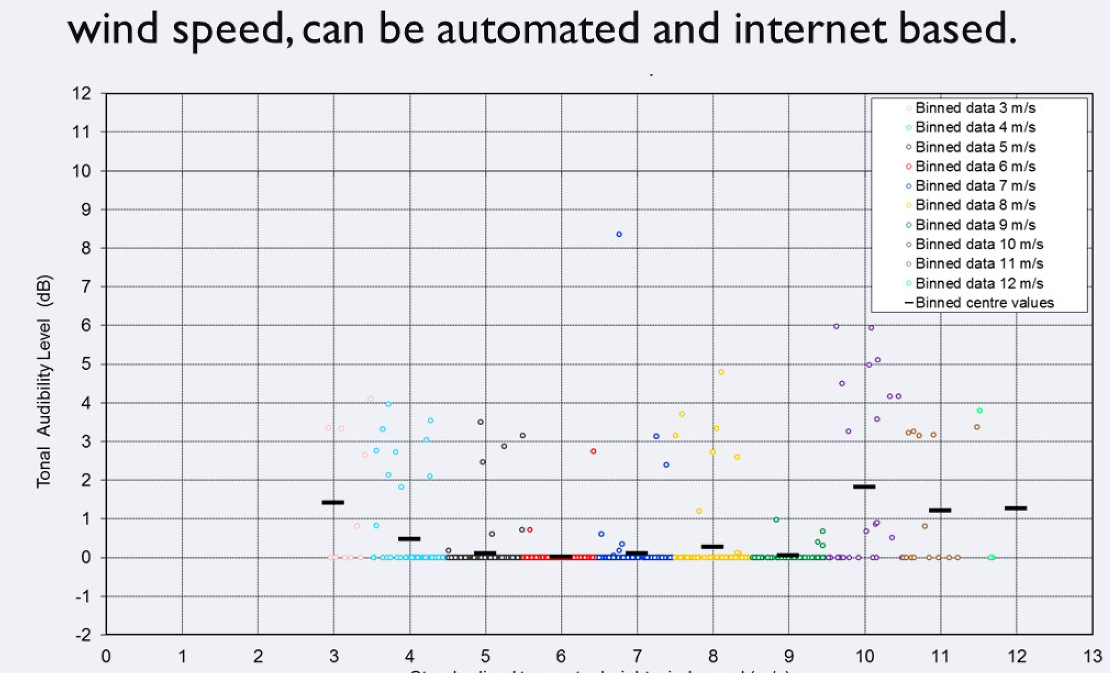
Audio recordings can be retained for subjective listening of key periods of interest, but are converted to compressed formats to limit transmission sizes.

The system architecture can vary depending on the installation capacities and communication facilities. In the case where the system can be connected via a rapid internet broadband connection, it may be possible to transmit the whole data to a server, where all more intensive processing can be undertaken ("**cloud-based processing**" architecture). In this case the results are still available in almost real-time and the automation of the processing and analysis undertaken means that results and audio recordings can be directly available.

When connected to mains power, such systems can remain in place for a long time without servicing visits to change batteries, reducing servicing costs, whilst the communication solutions put in place still allow a rapid evaluation of the results.

Example of a smart meter with *in-situ* data processing, including a rain gauge allowing exclusion of rain-affected periods

For example, the chart below shows an example of change in measured tonal audibility with wind speed. The production of such outputs, e.g. noise levels vs wind speed, can be automated and internet based.



Example output: change in tonal audibility with wind speed

Conclusions

The system architecture presented is considered by the authors to represent the state of the art in noise measurements, allowing an efficient study of a complex picture at operating wind farm sites. The information can be fed back directly to the site operator in order to provide fast diagnostic if required: this reduces delays and associated impacts on wind farm neighbours.

References

1. ISO 1996-2 – Description, measurement and assessment of environmental noise - Part 2, Determination of environmental noise levels (2007)
2. ETSU-R-97, the Assessment and Rating of Noise from Wind Farms, Final Report for the Department of Trade & Industry, September 1996. The Working Group on Noise from Wind Turbines, UK.
3. Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect, Renewable UK, December 2013.
4. Bass, Cand, Davis, Irvine, Leventhall, Levet, Miller, Sexton, Shelton. Institute of Acoustics Amplitude Modulation Working Group Discussion Document, Methods for Rating Amplitude Modulation in Wind Turbine Noise. www.ioa.org.uk (2015)
5. Measurements to assess the effectiveness of turbine modifications to reduce the occurrence of AM in the far-field, EWEA Technical Workshop, 9-10 December 2014, Malmö.

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