LONG-TERM ENVIRONMENTAL MONITORING AND NOISE SOURCE IDENTIFICATION

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Abstract: To control noise emission from any source, regulating bodies can adopt one of two strategies – physical controls specifying equipment types, silencers, barriers, etc. or performance-based controls specifying noise levels to be met at sensitive locations. The performance-based approach is generally preferred by both noise-makers (because it allows flexibility in designing noise controls) and affected communities (because it guarantees a noise level outcome). A major problem, however, is monitoring compliance confidently. The performance-based strategy generally requires accurate detection of the noise level due to a particular source, automatic monitoring of this level over a long period (often months or years), and fast (preferably real-time) access to monitored data. Techniques are becoming available to perform all these tasks, making performance-based noise conditions practical for a much larger class of noise sources. This article describes some recent developments in this field, and demonstrates the capabilities of a large noise monitoring system with source-detection capabilities.

1. INTRODUCTION

"It s ridiculous. Look at your meter — the BIRDS make more noise than my factory/road/mine/wind turbine." A very familiar comment which encapsulates one of the most difficult issues in the control of environmental noise.

There is, of course, nothing irrational about residents showing different levels of reaction to different noise sources (as the noise-maker above seems to imply). Nevertheless, it does present a problem for regulators. If limits for industrial and similar noise are set low enough to protect residents adequately, then almost invariably noise which meets or almost meets those limits will be very difficult to measure in the presence of other less annoying noises such as rustling leaves, distant traffic, lawn mowers and (yes) birds. Residents can easily tell the two types of noise apart, but until recently acoustic measurement equipment has not generally been up to the task.

In Australia, noise limits for industrial and similar sources are becoming increasingly more stringent and more detailed, as evidenced by the NSW Government's recently-released Industrial Noise Policy [1]. As the theoretical criteria become more strict, monitoring of compliance with these criteria becomes more difficult.

This paper describes some current approaches to the control of environmental noise, concentrating on noise from industrial and similar sources where the problem of compliance monitoring tends to be most acute. In particular, recent developments in noise monitoring technology bring the goal of real-time monitoring of noise from a specified source closer to reality, and one example of the use of these techniques is described in detail.

2. NOISE CRITERIA AND COMPLIANCE MONITORING

Standards for the control of general environmental noise in Australia are summarised by Burgess and Macalpine [2]. These standards are generally invoked at the point of approval of a project, at which time the proponent is required to demonstrate that the level of noise due to the project will be within the criteria. In most States, the requirements are broadly similar to the "intrusiveness" and/or the "amenity" criteria in the NSW Industrial Noise Policy :

$L_{Aeq,15min}$ <= Rating Background Level + 5 ("intrusiveness") and
$L_{Aeq,Period}$ <= Acceptable Noise Level ("amenity")

where:

- $L_{Aeq,15min}$ represents noise emitted by the source under consideration;
- the "Rating Background Level" is a measure of background noise in the absence of noise from the source;
- $L_{Aeq,Period}$ represents noise due to all industrial sources (but excluding transportation and natural sources); and
- the "Acceptable Noise Level" is a fixed value depending on the type of area and time of day.

Once it has been accepted that noise levels due to the project can meet the relevant criteria, the consent authority will then set down binding conditions intended to guarantee that the criteria are met in practice. There are two general approaches to setting these conditions.

First, the authority may simply require that all noise control measures such as barriers, silencers, etc. which were included in the proposal be installed. Under this approach, verification of compliance is very simple. It does, however, rely on (usually) theoretical calculations in the proponent's statement to ensure that these measures are adequate. The accuracy of such calculations is typically ± 5 dBA [3], so this procedure is adequate where compliance issues are not critical and/or where conservative assumptions have been made in calculations. In critical cases however, residents often demand that the assumptions be confirmed by actual noise measurements. Plant operators also prefer measurement-based conditions, because it allows flexibility in cases where, for example, actual operations may be less noisy than predicted, or new noise control technology may become available after consent is granted.

Alternatively (or in addition), a consent authority may require a regime of noise monitoring designed to determine whether the criteria are being met. Once again, monitoring traditionally takes one of two forms.

- Long-term unattended monitoring uses automatic data loggers, which are relatively inexpensive and easy to deploy. These may record only noise level index, or they may include methods for recording short sections of audio signal, to allow later identification of the most important noise source(s) by an operator. Some monitors can be interrogated remotely via a modem, and thereby for a semi-permanent system. Unless permanent power (mains or solar) is available their batteries need to be changed regularly. Aircraft noise monitors generally incorporate some form of event discrimination, based typically on rise time and duration, to assist in separating aircraft noise from other events. For other types of noise, such discrimination is much more difficult, so unless very large sections of audio signal are recorded, it is generally not possible to be sure that recorded noise actually emanates from the source of interest.
- Attended monitoring allows more positive source identification by an operator, although it may still not permit a confident measurement of the level of noise from a specific source, unless that source is dominant (over other noise sources) for at least short periods during the monitoring. This form of monitoring is necessarily short-term, and hence may miss periods of high noise emission. It can also be quite expensive, particularly if multiple monitoring sites are involved.

Neither of the above forms of monitoring can necessarily provide an unambiguous answer as to whether or not noise from the source of interest exceeds a specified criterion. This explains the reluctance of consent authorities to rely solely on monitoring as a tool for enforcement of noise conditions.

3. NOISE SOURCE IDENTIFICATION

Separating a complex signal into its independent, uncorrelated component sources is termed the "blind source separation" problem. It is in principle soluble, and considerable work has been performed recently on finding computationally efficient methods to perform this task.

For acoustic applications, techniques have been investigated which allow recovery of the complete time waveform of each source. Approaches which provide an unambiguous solution for spatially-separated sources, such as that described by Choi [4], generally require at least as many microphones as there are possible sources. Alternative techniques such as that described by Pearlmutter and Parra [5] require only one microphone, but detect different components of a sound (such as tonal and non-tonal components) rather than different spatially-separated sources. Both these techniques require "training" of the system to converge on an optimal source decomposition, and both involve computing requirements which would preclude real-time use with current-technology systems. Nevertheless, they offer significant scope for future developments which would allow separation and actual "listening" to specific component sources, as well as measurement of properties such as the level and time-variation of the signals.

Another approach relies on detecting a "noise signature" for particular sources. Some progress has been made in identifying particular types of vehicle in a traffic stream [6,7]. Variations on these procedures involve simple filtering of a signal to remove a known source such as insects, and detection of the noise signature from, for example, an aircraft in order to exclude this noise from monitoring results. These and similar systems however, depend on prior knowledge of the temporal and/or spectral characteristics of all sources to be detected or excluded, and assume that sources of interest will differ significantly from others in these characteristics.

A technique developed by the author [8] allows real-time detection of the direction of noise sources and assessment of the level of those sources, using a three-microphone array. The system requires prior knowledge of the direction of a source of interest, but this is generally known in environmental noise monitoring. Each measurement includes all noise in the specified range of directions, including any extraneous sources which happen to be in that direction. Nevertheless, because the technique can be implemented continuously and in real time, it offers the possibility of significantly improving the specificity of unattended noise monitoring systems.

The following section describes the implementation of a large, permanent system for monitoring noise from an open-cut coal mine. The system incorporates directional monitors, storing of audio signals, and the possibility of obtaining real-time audio and directional information from any monitor, as well as validation using traditional attended and unattended monitoring. It is believed to represent the current "state of the art" in environmental noise monitoring, and points toward future directions and possibilities.

4. NOISE MONITORING AT MOUNT ARTHUR NORTH COAL MINE

Noise Requirements

The Mount Arthur North coal project is located south-west of Muswellbrook, NSW. It includes an open-cut coal mine producing up to 15Mt of run-of-mine coal per year, together with associated processing facilities and a rail loading point. There are isolated residences within approximately 2km of the mining areas, and relatively dense development within approximately 4km (Figure 1). There are also a number of other existing coal mines in the area which are audible at many of the residences potentially affected by Mount Arthur North.

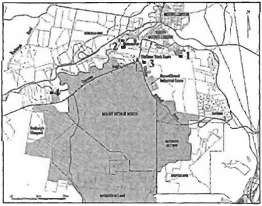

Figure 1 Location of Mount Arthur North mine and directional noise monitors

Figure 2 A directional noise monitor

The project received development approval in May 2001. As anticipated, environmental noise was a major issue during the assessment process. The relevant approval conditions are framed fundamentally in terms of compliance with criteria, rather than simply noise control measures to be carried out, although some specific measures are also required. The criteria are expressed as:

- an $L_{Aeq,15min}$ noise level not to be exceeded for more than 10% of monitoring periods in any season. This criterion applies to noise from the Mount Arthur North project alone; and
- a long-term $L_{Aeq,Period}$ noise level (where "period" represents day, evening or night) not to be exceeded by the cumulative noise from all industrial sources in the area. (The relevant sources are largely mines.)

A noise monitoring program designed to test compliance with these criteria was approved by the NSW EPA.

The Monitoring System

The Mount Arthur North noise monitoring system serves three functions:

- provision of data to demonstrate compliance with the above criteria, for inclusion in quarterly and annual reports;
- continuous updates of recorded noise levels over any selectable period, available on-line at any time, to provide "early warning" of possible problems; and
- a real-time display and listening function to provide operators with immediate feedback on current noise levels, allowing site operations to be altered to avoid potential exceedances of criteria.

The major part of the system consists of four directional noise monitors, installed at locations shown in Figure 1. Each monitor consists of three microphones located at a height of approximately 4.5m from the ground (Figure 2). The microphone outputs are connected to a computer located in a small shed adjacent to the monitor, which performs the following functions:

- detects the direction and level of noise sources once per second, based on processing of the three microphone signals;
- accumulates the L_{Aeq} noise level arriving from each five-degree increment of angle, and saves the accumulated levels every five minutes;
- accumulates non-directional statistical noise levels as for a standard unattended noise logger, and saves every five minutes;
- saves audio data in WAV-format files of any specified length, at specified time intervals and/or when the total noise exceeds a trigger level for a specified length of time;
- on request, provides real-time streaming audio to another connected computer; and
- performs an automatic test of the microphone functions once per day.

Each of the monitors is connected through an 8Mbps microwave link to the site's computer network. Two separate programs, which may run on any computer on the network, can interrogate the monitors.

First, a real-time inspection program can display the noise level and direction of sources being detected at any monitor, the total L_{Aeq} noise level since the last logging interval and the L_{Aeq} noise level from sources within a specified range of angles. Figure 3 shows a typical display from this program. Simultaneously, audio signal from the selected monitor is fed to the computer's sound card. This allows an operator to listen to noise at any monitor, while tracking both the noise level and the direction from which it is arriving. If a source is identified as being associated with the mine, and is creating

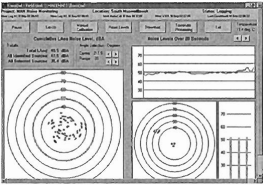

Figure 3 Typical real-time display showing noise level vs time (upper right), instantaneous sources detected (lower right) and cumulative noise level by five-degree segments (lower left)

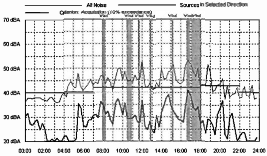

Figure 4 Noise levels for a single day, showing total noise and noise from a specified range of angles. Wind-affected data are shaded.

unacceptably high noise levels, corrective action can be taken immediately.

Second, an automatic downloading program retrieves data from each monitor every five minutes, and updates a database of stored noise levels. This database contains a record of L_{Aeq} noise levels from each of 72 five-degree angle increments from each monitor every five minutes, as well as statistical noise levels, calibration readings and other information. Stored WAV files are also downloaded, and may be compressed to MP3 or similar format and saved to disk. At present the database contains information from over a year's measurements. Information from meteorological measurement stations at each of the monitoring locations is stored in the same database, to allow exclusion of data affected by high wind or rain.

A third program generates reports from the database, oriented toward demonstrating compliance or otherwise with the mine's noise criteria. Figure 4 shows information from a particular day, while Figure 5 shows results over a two-week period.

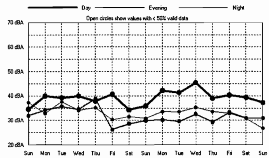

Figure 5 Recorded noise levels over 14 days, showing the noise level from a specified range of directions which is exceeded for 10% of 15-minute time periods during the day, evening and night periods on each day

At the time of writing this report the monitoring system has been installed and running for over a year, during which time extensive testing and development has been carried out. Mine operations during that time have been largely construction-oriented. The effectiveness of the system in monitoring and controlling noise from full-scale mining operations will be tested over the first six months of 2003.

5. FUTURE DIRECTIONS

The Mount Arthur North noise monitoring system represents a complex, "high end" system designed to support performance-based noise conditions of approval in a large project where noise implications are critical. Identification of the source of monitored noise is crucial to its function, and the use of directional monitors represents a large step forward in this regard. Equally important is the integration of noise monitoring data into the site's computer systems, to take advantage of on-site distributed processing and information dissemination.

Based on this experience, two future trends can be predicted. First, "high end" systems will develop even more capabilities for automatic source detection. These would combine directionality with noise signature profiling, and eventually "blind source separation" programs to automatically recover the full audio signal of each independent source. Wilkinson Murray is already undertaking some work on such combined systems.

Second, source-detection capabilities will become available in less expensive "low-end" monitoring systems designed for short-term use. At present the major hurdle to this development is the power requirements of computer systems necessary for real-time data processing. While a standard noise logger can operate for several weeks from a battery power source, systems capable of complex number-crunching can only operate without mains power for less than a day. Nevertheless, where mains power is available, directional monitors have been used successfully in temporary installations. Recent advances in low-power computing may extend the possibilities for battery-powered operation.

The advent of reliable noise monitoring systems with source-detection capability should give regulators and residents more confidence that the noise criteria specified in consent conditions can and will be met. It should also allow operators to demonstrate unambiguously that they are meeting their noise requirements. Both these developments represent a significant step forward in environmental noise control.

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