A SYSTEM FOR AUTOMATICALLY DETECTING THE DIRECTION AND LEVEL OF NOISE SOURCES

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Abstract

This paper describes an unattended monitoring system which allows environmental noise to be assigned to various directions of arrival at the measurement point. The system uses three microphones placed in a triangle about 0.5 metres apart. For each microphone pair, the cross-correlation between the signals is used to find values of time delay, and hence angles of approach of a noise signal, at which the received noise is at a maximum. Where all three cross-correlations give maxima at the same angle, a source is assumed to exist. L_{eq} *noise levels from sources within each 5-degree angle range are accumulated, and saved for post-processing.*

The system should have application where noise from a single source (such as a mine or industrial plant) needs to be monitored in isolation, or where some noise sources (such as traffic) need to be excluded from a measurement.

Introduction

A common problem in monitoring environmental noise is the difficulty in assigning the measured noise level to a specific source. This problem becomes acute where the monitoring is performed to check compliance with legislative requirements or conditions of consent, and often results in ambiguity which hinders the enforcement of these conditions.

In addition, some policy guidelines require assessment of noise from specific sources only. For example, in determining certain noise criteria the NSW Government's Industrial Noise Policy requires measurement of noise from "industrial" sources only, excluding noise from traffic and other sources.

Current methods of assigning measured noise to a specific source include the use of time-history or spectral information, the use of short sections of recorded audio signal and, ultimately, full-time attended monitoring to identify the dominant noise sources at all times. All these methods have a limited range of applicability, and none is suited to routine monitoring of noise from general sources.

This paper describes a system for automatically detecting sources of environmental noise by direction, and recording the L_{Aeq} noise level arriving at the monitor from each detected source. The system thereby apportions the total L_{Aeq} noise level at the monitor location into directional components, allowing:

- accurate monitoring of noise level compliance for a source in a known direction;
- exclusion of noise arriving from certain directions; and/or
- determination of which of a number of sources is the dominant contributor to noise at the monitor location.

Methodology

Operating Principles

The monitoring system is based on a principle described by Harris and Ledwidge[1] in which the direction of a sound source may be determined from the time delays between signals arriving at multiple microphones. These delays may in turn be found from the cross-correlation functions between signals from pairs of microphones.

When the same signal arrives at two microphones at different times, the cross-correlation function will have a local maximum at a delay equal to the time difference. The value of the maximum is related to the level of the signal arriving with that delay, by:

$$L_{sig} = L_{tot} + 10 \log(C)$$

where L_{sig} is the noise level of the signal, L_{tot} is the total noise level recorded in the sampling period and C is the value of the cross-correlation function at the relevant delay. The angle of arrival and the distance to the source are then related to the delay time, although for a single microphone pair these are not determined unambiguously. If noise arrives simultaneously from two directions, there would be two peaks in the cross-correlation function, and the estimated levels of both signals would be given by the above formula.

Peaks in the cross-correlation function also occur for other reasons. If the noise signal has peaks in its auto-correlation function (generally associated with a tonal or narrow-band signal), these will also appear in the cross-correlation. Maxima also occur simply due to the random nature of the signals involved. In addition, two closely-spaced peaks may appear as a single maximum, particularly for low-frequency signals or where one signal is significantly weaker than the other.

The detection system described here uses three microphones arranged in an equilateral triangle. Cross-correlation functions are formed between each of the three microphone pairs, and all local maxima in these functions are found. An algorithm then searches for sets of three maxima which could all represent a source in approximately the same direction, and at the same distance. The computed noise levels from all sources within a specified range of angles are accumulated, giving an estimate of the total L_{Aeq} noise level arriving at the monitor from that direction.

In some cases, the search algorithm will detect "spurious" noise sources based on a set of random maxima which happen to occur at time delays corresponding to a real noise source in some direction. However, such artifacts tend to occur in isolated noise samples, which are typically of 1-second duration, and experience indicates that their contribution to the L_{Aeq} noise level over an extended period is negligible.

Of more concern is the non-detection of real sources due to one or more cross-correlation peaks being "buried" by peaks from higher-level sources with a similar delay. This may result in some sources not being detected at all, or in the L_{Aeq} level due to low-level sources being underestimated, because the sources are detected in some 1-second samples but not others. This issue is discussed further below.

Implementation

In practical implementation of the system, the three microphones are located in an equilateral triangle with side L = 0.5m. Signal from each microphone is A-weighted and sent to an analogue-to-digital converter sampling at 44.1 KHz. One second of audio data is accumulated, and then processed while the next sample is accumulated. Using a 1.5GHz processor and optimised calculation routines, processing can be accomplished within 1 second, allowing real-time operation with no loss of data.

Data processing consists of the following operations.

1. For each of the three microphone pairs, a cross-correlation is formed between the two signals, with delays ranging from $-L/c$ to L/c where c is the speed of sound. Note that because the value of c may change significantly with temperature, a temperature sensor is incorporated into the system and queried on a regular basis to update the value used in calculations.

2. The processing algorithm finds all local maxima in each of the three cross-correlation functions, and searches for "matching" sets of three maxima which could represent the same noise source. The tolerance used in matching source angles is typically set at 10°. Each maximum is assigned to at most one source – where two assignments are possible, the assignment giving the highest source level is taken.

3. The process described above is applied in each one-second sample period. The noise level of all sources detected in each 5° angle range is accumulated on an energy basis, giving an estimate of the L_{Aeq} noise level arriving at the monitor from each of 72 directions. These accumulated levels are typically recorded every 5 minutes throughout a monitoring period. The results can be displayed in real time, and can be post-processed to give noise levels over any relevant time period.

Note that the algorithm used assumes all noise sources are at an angle of less that 15° above the horizontal, and at a distance of at least 3L from the centre of the microphone array. Noise from other sources would form part of the "unassigned" component of the total measured noise.

Testing

Tests of the system were conducted in an open park, using loudspeaker sources located approximately 25 m from the microphone array. Existing ambient noise was generally due to distant traffic, birds and similar sources. Its level was quite constant throughout the testing period at 54 – 55 dBA L_{Aeq}, and the direction of origin was diffuse, although there was a tendency for concentration in one 30° range of angles, corresponding to a distant major road.

In the first series of tests, the noise level from a single loudspeaker was initially set to be much higher than the ambient level at the monitoring location, so that the noise level from the source (broad-band pink noise or recorded traffic noise) could be taken to be the total measured level. The source output (as monitored by a sound level meter close to the speaker) was then reduced until its level at the monitoring location was at or below the ambient level. The noise level originating from the source direction, as measured by the directional monitoring system, was then compared with the actual known noise level from the source. This situation is considered to be representative of typical noise monitoring tasks, where the noise level from a source of interest is at or below the ambient L_{Aeq} level.

Typical results of this testing are shown in Figure 1. (More detailed results are available from the author.) As the source noise level is reduced, the total measured noise level at the monitor first reduces and then stays stable at the ambient level of 54 – 55 dBA. However, the level detected from the source direction continues to give an accurate indication of the true source level (to within 1 dBA) for source levels at least 5dB below the ambient. As the source level decreases further, the "measured" level drops below the true level because in some 1-second samples the source was not detected. This behaviour was repeated for other types of source noise including octave-band filtered pink noise (at all frequencies) and recorded impulsive noise.

The second series of tests was more stringent, using two loudspeaker sources separated by an angle of approximately 25° at the monitor, set to produce different noise levels, both of which were significantly above the ambient. The noise level due to each source was measured individually, and then the two were measured simultaneously using the directional monitor, over a period of 30 seconds.

Results of this test are shown in Figure 2, for different combinations of noise types from the two speakers and different relative noise levels. In all cases the monitor detected two sources in the correct directions, to within 10°. Figure 2(a) shows the measured noise level for the louder of the two sources in each test, compared with its true level. In all but one case, the level of the louder source was accurately measured to within 1dBA, in the presence of noise from the second source.

On the other hand, the true L_{Aeq} noise level from the lower-level source was consistently underestimated, due to the source not being detected in some samples, as described above. In situations such as this, the "measured" level for lower-level sources should be regarded as a lower limiting value. An upper limiting value can be set by assuming all "unassigned" noise is actually associated with the source in question.

Figure 2(b) shows the range of estimated noise levels obtained in this way. The range covers the true source noise level in all cases, although sometimes the range is admittedly very large. Best results were found when both sources were recorded traffic noise, which varies with time, rather than one or both being a constant level of pink noise. This is considered more likely to be representative of typical measurement situations. For the traffic/traffic case, a secondary source which is over 10dBA below a dominant source and separated from it by 25° in angle could be identified, and its noise level estimated to within a range of about 6dBA.

Operation

At the time of writing this paper, a permanent directional noise monitor has been installed for approximately two weeks close to a coal mine in the Hunter Valley. Figure 3 shows a typical example of the results obtained. In this 5-minute monitoring period, from the total measured L_{Aeq} noise level of 39.5dBA, 38.4dBA could be attributed to sources detected by the system, of which 35.3dBA resulted from sources in the range of angles which is highlighted in the Figure (corresponding to a known source). It is hoped that further results from operating monitors can be presented at the Conference.

Conclusion

The system described in this paper provides a means of automatically assigning measured L_{Aeq} noise levels to sources located in specific directions. If one source is dominant during a 1-second sample, the level and direction of that source will be accurately recorded to within about 1dBA and 10° respectively. Sources which are not dominant will also be detected, but more care needs to be exercised in estimating their level, and in some cases it may be necessary to quote a range of possible noise levels.

It is hoped that a monitoring system such as that described here will allow more accurate identification of noise sources in the field, as well as reliable checking of compliance with regulations which limit noise emissions from specific sites.

Reference

1. Harris, R.W. and Ledwidge, T.J. Introduction to Noise Analysis, pp 62-63. Pion, 1974.

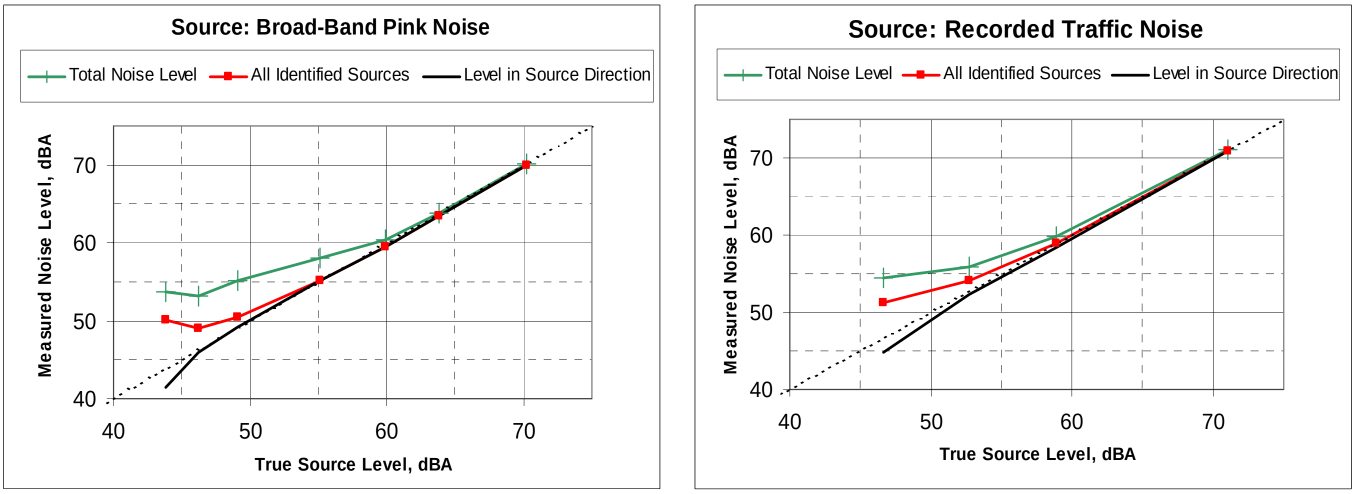
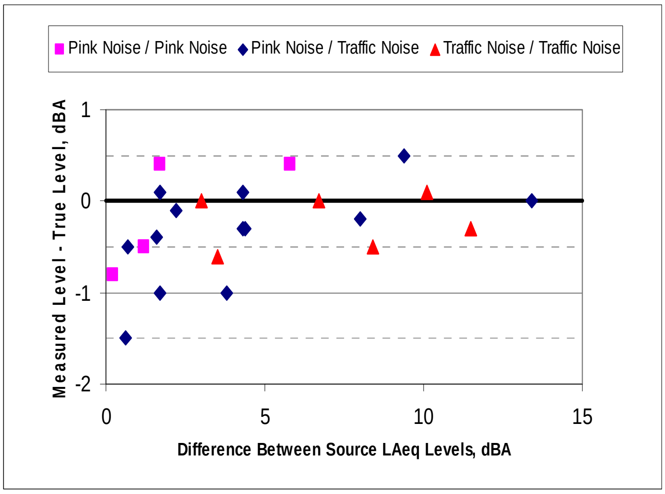


Figure 1 Detection of a Source in the Presence of Background Noise
(a) Broad-Band Pink Noise Source
(b) Recorded Traffic Noise Source



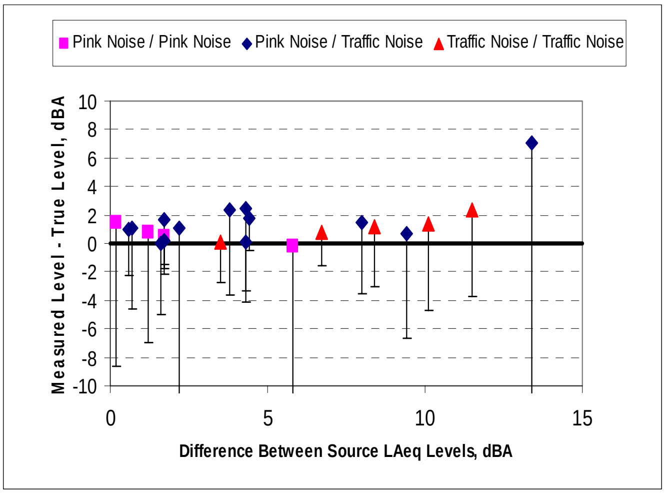


Figure 2 Detection of a Source in the Presence of Another Source
(a) Detection of the Higher-Level Source
(b) Detection of the Lower-Level Source

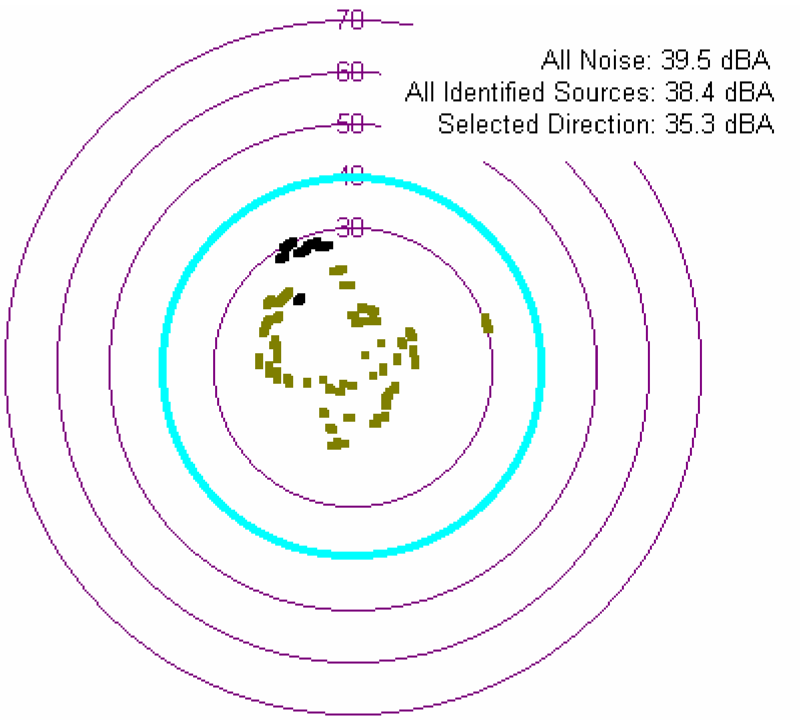


Figure 3 Typical Output from 5-Minute Sample of Environmental Noise