Proceedings of the Institute of Acoustics

AUTOMATIC NOISE SOURCE IDENTIFICATION

P Wright, I H Flindell

ISVR, Southampton University, Southampton SO9 5NH

1. INTRODUCTION

The recent Noise Review Working Party Report (1990) recommended "that research should be put in hand to formulate a common measure for the assessment of noise from the main forms of transportation". Current methods of assessment are based on considering each noise source separately, in some cases using different noise units. There are many situations where this approach could be considered an over-simplification because of the possible effects of background noise and multiple noise sources. There are also many situations where the presence of competing noise sources makes the measurement of the contribution from a particular noise source problematical.

Any common measure should be soundly based on the results of research into subjective response to complex noise environments, requiring that the individual contributions to the overall noise climate made by each significant noise source should be separately quantified. The aim of this new research will be to develop a general noise annoyance model which is capable of taking the various components of annoyance due to different noise sources and the many attitudinal and contextual factors which are present in any particular situation into account. Assuming that the relative levels of different contributing noise sources are found to be important, then it will be necessary to develop a simple means of field measurement which can separately determine these relative levels to be able to apply this knowledge in new standards and regulations.

Existing technology for unattended noise monitoring using sound level logging instruments can only determine overall noise levels without regard to source. This means that the microphones must be sited with considerable care to be reasonably certain of what is being measured. The aggregation of the separate contributions from different noise sources at most residential sites can be done at present only by using an experienced operator to identify sources and manually control an integrating or logging sound level meter system. This technique is extremely labour intensive, particularly where the sources are sufficiently variable to require extended monitoring durations. In some circumstances it is possible to analyse tape recordings or sound level logs at a later stage in the laboratory to assist with source identification, but this tends to be even more labour intensive than employing an experienced operator on site, and some loss of resolution or discrimination is bound to occur in comparison to on-site identification.

What is required is an unattended monitoring system capable of automatically identifying separate sources of noise and separately aggregating the noise level contributions of each to the overall noise climate. The device would not be required to provide absolute identification of noise sources, as an operator would always be present during the setting up phase. Thus the system need only be capable of classifying contributing noise sources as class A, B, or C, etc. relying on the operator to assign actual sources to each class.

While the majority of residential areas are mainly subject to main road and local road traffic noise over a wide range of noise levels, there are many noise measurement situations in which other noise sources are present to a greater or lesser degree. The extent to which the device would be required to separate out the contributions made by different noise sources which are present at the same time is an important determinant of the necessary degree of sophistication of the machine. An example of such a situation would be a site near to a busy motorway and an airport where aircraft noise events could occur at the same time as heavy trucks passing on the motorway, giving similar instantaneous noise levels and corresponding difficulties for contribution aggregation. Such a situation is by no means unusual and if it is to improve on existing instrumentation the critical requirement of the machine is that it must be able to provide a breakdown of a noise environment in terms of the contributions of various sources that may or may not be operating simultaneously.

2. POSSIBLE STRATEGIES FOR SOURCE IDENTIFICATION

2.1 Single Microphone Pattern Recognition

Ideally, the system should be no more inconvenient to use than a conventional sound level meter. A number of specialist systems based on temporal and spectral analysis of the output of a single microphone channel have been reported in the literature (1,2,3,4,5), and are generally capable of reliable discrimination between limited numbers of sources with clear distinguishing features, but there is some doubt as to the general applicability of such systems. The short Leq data logging technique (6) provides considerably more information than a conventional sound level meter system and allows for the aggregation of the contributions from each separate noise source but requires manual intervention to achieve source identification.

2.2 Experimental Work using a Single Microphone System

The experimental work carried out up to the present time was intended to investigate how well a single microphone recognition system could discriminate between the three major transportation noise sources; road traffic, aircraft and trains. The first step was to obtain 'clean' recordings of each of the noise sources using an 8 track portable recording setup. This allowed the effect of source to receiver distance to be investigated and provided a comprehensive database in the minimum time on site. Each site was carefully selected to avoid extraneous noise as far as possible and therefore each recording represented, for a particular distance, the optimum signal to noise ratio that could be achieved without travelling to very remote places. This ensured that any detectable spectral differences were 'real' differences.

2.3 Spectrum shape

All recordings were later analyzed in the laboratory to obtain time varying 1/3 octave, 1/12 octave and 1/24 octave spectra using a B&K type 2133 constant percentage bandwidth digital frequency analyzer. The broad aim was to investigate to what extent and in what respects railway, aircraft and road traffic noise exhibit spectral differences and to see whether any differences could be utilized to provide a basis for building up a set of templates for pattern recognition purposes.

These analyses revealed that there is considerable overlap between time varying spectra for the three different noise sources to the extent that any opportunities for identification using spectra alone would be very limited. Although spectrum shape depends on the precise nature of the source, the variability of spectrum shape within a particular type of source appears to be comparable to the differences in spectrum shape between different types of sources, thus limiting the value of spectrum shape as a significant feature for source identification. However, additional information may be present in the form of particular spectral details or 'features' characteristic of a particular source.

2.4 Spectral Features

In road vehicle noise a harmonic structure with a fundamental frequency at the engine firing frequency (normally below 150 Hz) is often present. This harmonic structure is often detectable by narrow band frequency analysis and is not normally present in railway and aircraft noise as the engines normally operate in different rpm ranges. Nevertheless there are some similarities between the engines fitted to heavy goods vehicles and modern light weight passenger trains. Analysis, however, revealed clearly how the presence of low frequency harmonic components due to power train noise depends on the vehicle operating conditions and therefore cannot be relied upon as a reliable identification feature. Road traffic noise measurement is more usually concerned with steady streams of traffic where the noise from several vehicles is contributing to the measured road traffic noise level at any particular time. It is unlikely that individual vehicle low frequency harmonic components would be separately identifiable under these conditions.

Harmonic structures are also often present in aircraft noise, though at higher frequencies. These structures are not separately resolvable at the typical distances where noise measurements would normally be taken except in the cases of some individual aircraft types. Aircraft engine high frequency tonal components are normally highly directional and are subject to considerable variation with aircraft thrust setting and the prevailing meteorological conditions. The harmonic components could indicate overflying aircraft noise, but the absence of such components does not indicate that overflying aircraft are not present. Another potentially useful spectral feature (detectable by cepstral analysis) depends on interference effects between the direct sound and the reflected wave from the ground surface near to the microphone causing a comb filtering effect which manifests itself as a ripple in the frequency domain. However, in many practical measurement situations this effect is not clearly evident and can easily be corrupted by reflections off other surfaces close to the measurement microphone.

Train noise spectra are generally dominated by broadband wheel/rail noise, with some contribution from diesel locomotives where present and under power. Each class of diesel locomotive produces its own characteristic sound whilst electric locomotives and electric multiple unit trains do not produce a separate locomotive sound. Use of continuous welded rail has on many lines removed the distinctive knocking noise produced by the wheels passing over bolted rail joints. The analysis did not reveal any particular spectral features that could reliably indicate the presence of a train.

A general spectral feature of all moving sources is the Doppler effect, a frequency shift which is dependent on the speed and direction of travel of the source. As the source approaches its near point to the microphone the energy is shifted up in frequency whilst having passed the near point the energy is shifted below the 'true' frequency. Consequently this effect will be more noticeable the greater the speed at which the angle of view is traversed by the source, and also if the sound contains a recognizable pitch.

2.4.1 Summary. There are a number of spectral shape and feature cues present in the noise characteristics of road traffic, aircraft, and trains which could potentially be used in source identification. Although these cues could be used by permanent noise monitoring stations or for highly specific purposes there appears to be insufficient consistency across a broad enough range of conditions for these cues to be used for general identification purposes. On the other hand, some of these cues may prove to be useful when employed in conjunction with other overall level, temporal and spatial cues.

2.5 Temporal Characteristics
The spectrum shape and feature analyses described above were carried out using a Bruel & Kjaer type 2133 frequency analyzer set to record multispectra with a linear averaging time of one second or less. Multispectra allow the time history in each frequency band and overall level to be plotted out separately in histogram form. This can give an indication of the total duration of a noise event, or an indication of the time during which the noise level is within a few dB of the maximum, either overall or in each frequency band. One problem here is defining a meaningful yet simple measure of event duration in view of the often irregular pattern of rise and fall in noise level while vehicles approach and recede.

The SEL of a noise event can be related to the maximum level in terms of the duration of an equivalent rectangular profile noise event with the same maximum level. This duration measure is of limited value as an identification parameter as the beginning and end of the event must be separately identified before it is possible to calculate the SEL. A potentially simpler measure of event duration would be the time above noise level points x dB below the maximum level. The main problem with this measure is that the averaging time for measuring instantaneous noise level must be selected with great care to avoid an excessively irregular noise level time history. Any such duration measure would depend on the vehicle speed and direction in relation to the microphone position, and it would require that the event is clearly discernable above the background noise at that site.

The results indicated that event durations for train and aircraft passbys, however measured, tend to occupy the same ranges for both sources and that for cars any individual passby duration is likely to be unmeasurable beyond a distance of 50m. Event duration is closely related to train speed and length or aircraft speed and the closest distance to the receiver during the pass-by and does not discriminate between these two sources.

AUTOMATIC NOISE SOURCE IDENTIFICATION

Subjective impressions of train and aircraft passbys suggest that the maximum levels in particular frequency bands do not occur simultaneously. These impressions are partly influenced by subjective impressions of pitch change due to Doppler and comb filtering effects, but they could also be influenced by different components of the overall sound dominating at different times during the event. However, in general the highest levels in each frequency band occur when the source is closest to the receiver, although the relative frequency content during the approach and recede phases may change. It appears that the human auditory system may be particularly sensitive to changes in frequency content during the event in comparison to its sensitivity to changes in instantaneous level.

2.5.1 Summary. In general, it seems likely that there are sufficient temporal and spectral cues available in most permanent noise monitoring situations to allow a single microphone automatic source identifying system to work satisfactorily but only where discrete events are separated in time with a good signal to noise ratio, and where there is some flexibility with microphone siting. A portable single microphone system intended for general use at many different sites would be extremely complex, and would require considerable on site experimentation before it could be made to work satisfactorily.

3. A MULTIMICROPHONE TECHNIQUE UTILIZING SPATIAL INFORMATION

Several techniques for utilizing the necessary spatial information were considered such as the use of directional microphones and adaptive beamforming processing. However, these schemes (a discussion of which is beyond the scope of this paper) were rejected in favour of a system utilizing remote microphones.

3.1 Automatic Source Identification using Remote Microphones

In this scheme a conventional instrumentation microphone is sited at the measurement or 'reference' position along with a data processing device and user interface. Remote microphones would then be placed near to each significant noise source to monitor the output of each. It is envisaged that the processing of the signal from each remote microphone need not be any more sophisticated than real time (one second linear averaged) 1/3 octave frequency analysis. This data could be calculated by a small processing device located with each microphone and transmitted in digital form to a central processor at the reference microphone with considerable economy in terms of required bandwidth. By using radio links in this way there would be little practical limitation with either microphone placement or with the remote to reference microphone distances.

3.2 Statistical Data Processing

The temporal pattern of instantaneous (1 second sampled) noise levels at the reference and remote positions would be used to identify events. Identified events would then be aggregated in event counters representing each source contribution at the reference microphone. Events would be classified by source, to determine which event counter for them to be aggregated in, and also by a number of additional features which relate to the energy contributions of those particular events. These features include the maximum levels at both microphone positions, the time at maximum at the remote identifier to determine event duration at maximum noise level, and the event approach and recede phase slopes. Possibly the best way to classify events in accordance with these parameters is to select from a number of prearranged event templates when searching for event patterns in the time histories at the two microphones. Event templates are effectively time domain windows which are moved along the data records until a least mean squares fit is obtained within certain tolerances. These event templates would be selected during a real-life field setup phase to correspond to the most commonly occurring sources at that site. Any event which does not conform to a preselected event template would be rejected as an unclassifiable event, and not counted as either a train or an aircraft.

There remains the problem of how to deal with two events occurring simultaneously. This problem may be solvable by considering event contributions at the reference microphone on a probabalistic basis. There would need to be some form of multi event template stored in the machine, but this could be constructed from existing discrete event templates without necessarily requiring field testing during a setup phase. The best fitting discrete and multi event templates would then be used to assign appropriate proportions of the overall sound energy measured at the reference microphone to the separate source aggregation counters. Statistical limits would need to be placed on this process to define unclassifiable events where event templates do not explain the overall level. To take the simplest case, where a discrete event is just emerging above the steady background level. Rules could be developed to require that only a small proportion of the measured energy at the reference microphone is assigned to that event in the first stages, increasing in proportion as the event rises to its maximum. This proportion at any particular time would be a function of the preselected event profile, of the measured level at the reference microphone and of any other events which are also occuring at the same time. It may eventually be possible to devise a scheme of rules for updating the event templates on the basis of systematic errors observed during such calculations, but such rules could only be developed after some experience with this type of system.

AUTOMATIC NOISE SOURCE IDENTIFICATION

4. CONCLUSIONS

A single microphone monitoring system would be feasible only within certain specialized contexts. To be useful for general environmental noise monitoring the system must utilize spatial information in order to resolve competing noise sources.

A technique utilizing spatial information via the use of remote microphones to instruct a reference microphone as to the activity of each significant noise source is being pursued. The contribution of each source to the noise at the reference microphone would then be estimated on a probabilistic basis following a period of in situ training of the machine. The precise operational details of this scheme will evolve from the work currently being carried out to establish the best means of statistically processing the multichannel information generated by such a system.

5. ACKNOWLEDGEMENT

This work was carried out at ISVR under contract with the Building Research Establishment as part of the DoE environmental noise research programme.

6. REFERENCES

[1] D.W.Thomas, 'Vehicle Sounds and Recognition', in *Pattern recognition: Ideas in practice*, B.G.Batchelor Ed. New York: Plenum, 1978. pp. 333-361
[2] P.Moukas et al. 'Automatic identification of noise pollution sources', *IEEE transactions on systems, man, and cybernetics*, vol. SMC-12, no.5, September/October 1982
[3] P.Moukas, 'Noise pollution analysis and recognition', *PhD. dissertation*, Dept. Systems Science, City University, London, February 1982
[4] I.Yamada et al. 'Acoustic recognition of aircraft types in flight', *Journal of the Acoustical Society of Japan* (E) 6, 3 1985
[5] R.H.Cabell et al. 'The identification of helicopter noise using a neural network', *American Institute of Aeronautics and Astronautics* AIAA-90-3973-CP (1990)
[6] B.F.Berry and A.D.Wallis, 'The role of short - term LAeq in problem areas of environmental noise measurement', *9th FASE Symposium*, May 7 - 9, 1991, Balatonfured Hungary.