Proceedings of The Institute of Acoustics

THE IMAGING OF MOVING SOURCES WITH THE COARSE-FINE ACOUSTIC TELESCOPE

DR. JOHN BILLINGSLEY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING,
PORTSMOUTH POLYTECHNIC

The coarse-fine technique is based on the cross correlation of two time-series per image point, formed by summing microphone samples subjected to appropriate delays. When the source is known to be moving, the image points can be made to move in a corresponding way by using delay values which themselves vary with time. In addition to removing 'motion blur' from the image, the technique eliminates doppler frequency shifts.

1. INTRODUCTION

In 1975, tests were conducted with an equispaced telescope on a jet engine mounted on a spinning rig. Data blocks were acquired on successive revolutions, triggered at the same spatial point, so that the results could be accumulated over sufficient data to achieve a meaningful average. It was clear that even over the length of a single data block, considerable 'motion blur' would be present, and so a technique was developed to 'pan' the telescope image with the movement of the source. The results of the successful application of this technique were contained in a company report, but the technique itself has been hitherto unpublished. With the development of the coarse-fine array, a corresponding method allows the tracking of moving sources. The improved resolution of the coarse-fine array then suggests its use for fly-over tests, where multi-pass accumulation of results cannot be used, and where 'panning' will allow a sufficient time-span to build up an acceptable time-bandwidth product.

2. THEORETICAL BASIS

A single source at $\underline{x}_o$ can be represented by

$$q(\underline{x},t) \equiv q(t)\ \delta(\underline{x} - \underline{x}_o).$$

The signal received by a microphone at $\underline{y}$ is then given by

$$\frac{1}{|\underline{x}_o - \underline{y}|}\ q(t - \frac{|\underline{x}_o - \underline{y}|}{c})$$

If $\underline{x}_o$ is in motion with respect to $\underline{y}$, the Doppler shift may be observed by differentiating the contents of the brackets

$$\frac{d}{dt}\ (t - \frac{|\underline{x}_o - \underline{y}|}{c})$$

$$= 1 - \frac{\dot{\underline{x}}_o \cdot (\underline{x}_o - \underline{y})}{|\underline{x}_o - \underline{y}|\ c},$$

representing a time-dilation or contraction of the source function dependent on the radial component of source velocity. The telescope algorithm is based on shifting the received microphone signals by an amount equal to the transit delay, so that in the reconstructed time-series, the value attributed to time t is the sample taken at time $t + \frac{|\underline{x}_o - \underline{y}|}{c}$. Provided that a time-varying set of shifts can be used, which track the changing value of $\frac{|\underline{x}_o - \underline{y}|}{c}$, the signal contributed by each microphone will be of the form

$$\frac{1}{|\underline{x}_o - \underline{y}|}\, q(t),$$

the signals will reinforce as for the static case, and no Doppler effect will remain.

For the coarse-fine array, two such time series are constructed, one for the fine array in which the microphones have unit spacing and one for the coarse array, which abuts the fine array and has one microphone in common with it, and which has microphone spacing greater by one unit than the entire length of the fine array.

3. THE COMPUTATIONAL TECHNIQUE

The results obtained by the acoustic telescope are conventionally presented in terms of intensities at 36 source points, this having been arbitrarily chosen as one dimension of the results array. For each source point, there is a vector of entries in the 'delay table', representing the distance delays to each of the microphones, thus when constructing a signal time-series for the i^{th} source point, delay d_{ij} is applied to each sample from the j'th microphone.

When the source under inspection is a jet engine, the source points of interest lie on the jet axis. When the engine moves, it moves along the jet axis. In the interests of resolution, source points for the results are chosen to be sufficiently close that only at the highest frequencies considered will the change in delay for a given microphone from one source point to the next represent a phase-shift of more than a fraction of a cycle. The motion of a moving source may thus be quantised in terms of the 'results points'. As it moves along the axis, changing columns of the delay table are invoked to mark its progress, and in the resulting time series some microphone contributions will be time-expanded or others time-contracted to obtain a dynamic match of the source time-function.

Each results point will now use a number of columns of the delay table, and this must clearly be provided with extra 'width' to accommodate the 'panning movement The array dimension was accordingly increased to 64 columns, allowing a 'panning length' of 28 results points. This meant that an image could be built up over the time taken for the engine to traverse three-quarters of the distance represented by the length of the results array.

By time t, a source point initially at x_i will have progressed to x_k, where $x_k - x_i = vt$,

i.e. $k = i + \frac{vt}{\delta x}$ then rounded to the nearest integer.

Thus for the i^{th} source point and the j^{th} microphone, the delay value d_{kj} is now used, where $k = i + \frac{v}{\delta x}\ t$. Since the value $\frac{v}{\delta x}\ t$ is common to all the delays, its value is calculated separately as a double-precision integer and fraction.

4. IMPLICATIONS FOR FLY-OVER TESTS

When the source is distant from the microphones, the delays must be reduced by some constant to avoid wastage of much of the sample data. The result then corresponds to the sound issuing from the source at a slightly earlier time, of no consequence for a static source. When the source is moving, however, an 'alibi' error could be introduced unless a (readily calculable) correction is applied. More important is the problem of an extended source region. For static distributions, individual columns of the delay table can be adjusted, either to economise on the time-spread of data samples within each block or to minimise the statistical time-spread influence of off focus sources (as presented by Teo[2]). When the source is moving, however, the relationship between different columns of the delay table must be preserved, which could result in a spread of delay values which might exhaust the computer storage capacity.

The signals will almost certainly be recorded on magnetic tape, and in theory large delays could be achieved by varying the time of digitising on replay. However, this presupposes the possibility of repeatedly finding the same place on the tape with an accuracy of a few microseconds. A pulse-interval encoding technique for an analog multi-channel recorder has been proposed and would have been realised but for the shortcomings of a subcontractor. However it is now quite clear that a recording method based on the use of a 'domestic' video recorder can provide digital quality recording with precise sample retrieval much more economically than an analog machine.

There remains the problem of the calibration necessary to achieve the increased performance of the coarse-fine array. The loudspeaker or 'thunderflash' methods are unlikely to prove expedient for establishing focus positions at a height of a hundred feet or more! Provided that good initial accuracy of microphone placement has been achieved and that the height and initial location of the aircraft are established to within a few metres, the source distribution of the aircraft itself can be used to tune the telescope to a fine focus much as would be performed with an optical camera. During the spinning rig tests brief images at each end of the panning range were compared to determine fine tuning adjustments of the tracking speed and this technique is easily applied to the fly-over case.

5. CONCLUSIONS

Techniques originally developed for spinning rig tests can be readily transferred to the coarse-fine telescope allowing its large ratio of alias length to resolution width to be exploited for fly-over tests. The image can be integrated over a substantial range of movement giving true moving-source

THE IMAGING OF MOVING SOURCES WITH THE COARSE-FINE ACOUSTIC TELESCOPE

imaging as opposed to the technique of monitoring a fixed point as it is traversed by the source. The coarse-fine method requires only the re-deployment of existing microphone equipment used with newly developed software, but for fly-over tests it is probable that new recording techniques will be desirable.

6. ACKNOWLEDGEMENTS

The work has been supported by Ministry of Defence Contract No.   and by the Department of Electrical and Electronic Engineering of Portsmouth Polytechnic. The development of the equispaced telescope for spinning rig applications was the result of team work by the author, J.L. Moughton and R. Kinns.

7. REFERENCES

1. J. Billingsley and R. Kinns, 1976, Journal of Sound and Vibration. 48, 485-510 "The Acoustic Telescope".

2. T.J. Teo and J. Billingsley, Institute of Acoustics Colloquium on Noise Source Location, Portsmouth, May, 1981. "The need for calibration in the coarse-fine acoustic telescope".

3. J. Billingsley, Cambridge Noise Research Unit Memo CNRU/JB/77. "Application of the Acoustic Telescope to the Observation of Moving Phenomena".

4. J. Billingsley and H. Purvis, Cambridge Noise Research Unit Memo No. JB/HP/84. "The Observation and Analysis of Moving Acoustic Source Distributions".