TUNING OF AUTOMATIC SIGNAL DETECTION ALGORITHMS FOR IMS STYLE INFRASOUND ARRAYS

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ABSTRACT

Design specifications for infrasonic arrays that comply with IMS requirements stipulate at least 4 sensors in a centered triangle configuration with maximal separation between sensors of between 1 to 3 km. Such a design is considered to be optimal for the detection of infrasound signals from explosive sources with yield down to around 1kT that are within a distance of around 3000km from the receiver. Automatic algorithms used for signal detection need to be optimized for both the signals of interest and the particular geometry of the IMS style array.

A research program nearing completion at the Center For Monitoring Research has been designed to produce automatic algorithms that are optimal with respect to signals and array geometry. Synthetic waveforms generated using Pierce's normal mode algorithm, designed to be representative of the infrasound signal from a 1-kT blast several thousand km from the receiver, were used to establish the Receiver Operator Curves (ROC curves) for the infrasonic signal detection algorithm in use at the Prototype International Data Centre (PIDC) in Arlington Virginia. The synthetic signals were implanted into conventional array channel data using an implant strategy that allowed the signal to noise ratio (SNR) of the signal to be specified in a fashion that accounts for the spectral composition of the background. SNR values ranging from 0.01 to 100 were used in the study to map out the ROC curves.

The PIDC infrasonic detection algorithm is known as a 'coincidence-detector' which relies on both the Fstat (Fischer Statistic), and the ratio of the L1 norms of a Short Term Average (STA) data window to that of a Long Term Average (LTA) data window, exceeding pre-determined threshold values simultaneously before a detection is declared. Such a detection algorithm provides a number of tunable parameters, such as three independent thresholds, STA and LTA times and the gap time separating the two, that can be used to explore the tradeoff between detection and false alarm rates necessary to generate ROC curves. The False Alarm Rate (FAR) places a control on all ROC curves, and the FAR value chosen for this exercise was set at 30 per day.

OBJECTIVE

Automatic signal detection algorithms of the variety in use at the Prototype International Data Centre (PIDC) for the processing of infrasound data have a number of 'tunable' parameters that can be chosen to enhance the Detector performance on signals considered to be of interest from a CTBT monitoring perspective; it may also be possible, by manipulating these parameters, to reduce the detection rate on signals generally not of interest, such as microbaroms and other natural forms of clutter. The main objective of this exercise, therefore, is to determine the optimal set of detector parameters for the automatic infrasound signal detector in use at the PIDC. The analysis will, for the present, be confined to data that conforms to IMS specifications, i.e., it is recorded on a 4-sensor centered-triangle infrasound array with sensor spacings of between 1 to 3 km on each side, and the sensor response will be assumed to be flat from 0.02 to 4.0 Hz.

The PIDC infrasound detector is known as a coincidence detector and has two major components. The first is a slowness-plane discretization that calculates two beams, an Fstat beam and a traditional beam directed at each point in the slowness plane. Both the Fstat, and the ratio of the L1 norm of a Short Term Average (STA) window to that of a Long Term Average (LTA) window on the traditional beam are required to achieve threshold values simultaneously before a detection can be declared. The second component of the Detector is a vernier-fk module that refines the slowness plane location of the signal. An additional threshold is placed on the coherent signal to noise ratio at the back-end of the vernier-fk module. Any signal is required to achieve this threshold value before a detection is declared. With such a Detector design, it becomes possible to devise a strategy that will reveal the optimal set of detection parameters for signals of interest. A tuning exercise of this kind culminates in the determination of Receiver Operator Curves (ROC) that provides a measure of the Probability of Detection (PD) as s function of Signal to Noise Ratio (SNR).

RESEARCH ACCOMPLISHED

In meeting this objective it was determined that the following steps constitute a workable Detector tuning strategy:

1. A suitable signal, representative of the acoustic signal generated by a 1-kt explosion located several thousand kilometers from the receiver is acquired.
2. One hundred hours of IMS-style array data, representative of a variety of ambient conditions, is chosen in which to implant the signal.
3. A method for implanting the signal time-series data into the background time-series data such that a pre-determined Signal to Noise Ratio (SNR) is achieved is determined.
4. Suitable definitions of Probability of Detection and False Alarm Rate are found
5. A method of parameter-variation is developed and executed to determine the tuned parameter list.
6. A method for establishing the ROC curves that provides Probability of Detection as a function of Signal to Noise ratio is determined.

Each of these tasks will be considered individually.

SignalData

The signal chosen for the tuning/implant exercise is a synthetic signal generated using the Pierce nomal-mode algorithm (Pierce, 1970) and was created via the InfraMAP toolkit (Gibson, et al., 1999). Six hundred modes were used to generate a signal that is considered to be representative of the acoustic signal generated by a 1-kt explosion nominally 1000 km from the receiver. The signal waveform is shown in Figure 1, and the Power Spectral Density is shown in Figure 2.

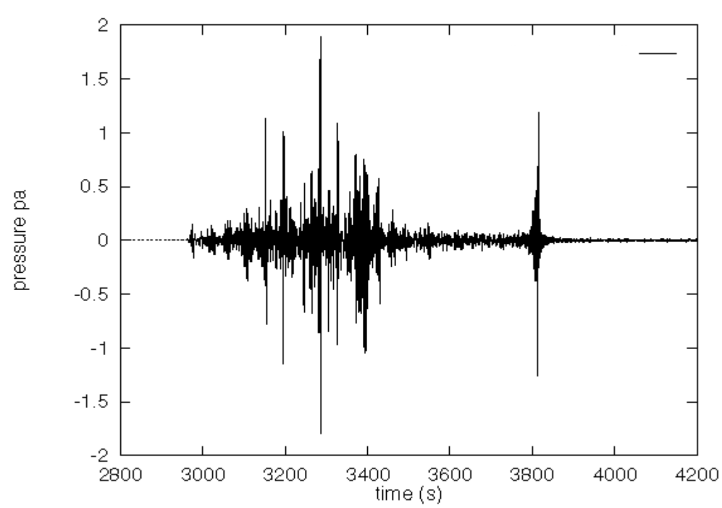


Figure 1: Synthetic signal representative of 1-kt source, nominally 1000 km from receiver.

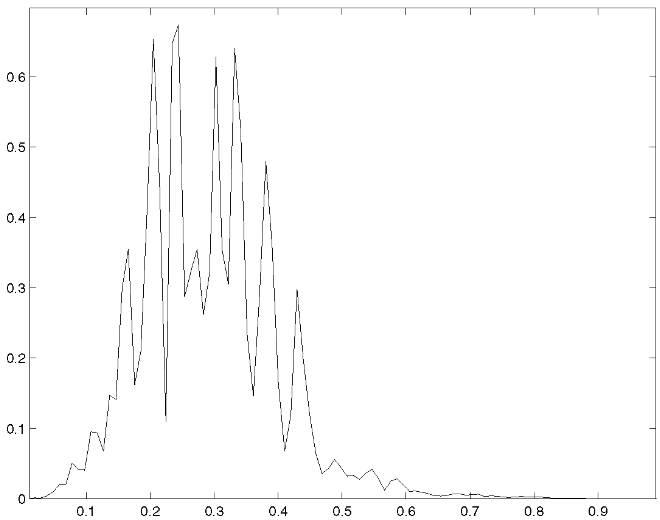


Figure2: Power Spectra of signal displayed in Figure 1.

Background Data

Ninety-Six hours of DLIAR array data were chosen as background data in which to implant the signal. The DLIAR array is an IMS-style array located in New Mexico and has 4 sensors in a centered triangle arrangement with approximately 1.2 km sensor separation along each side. Data from February 21 through 24, 1998 were chosen as background data as it represented a variety of ambient conditions. Additionally, analyst review indicated that few natural or man-made signals were present although some significant microbarom activity occurred. The extent to which microbaroms are present is revealed in Figure 3, which shows the speed, azimuth, and *Fstat* as a function of time for the four-day interval for periods ranging from 3.0 to 8.0 seconds. Days 1 and 4 have strong microbarom activity, while day 3 is almost completely devoid of activity. It is if interest to note that, even on kilometer-size arrays, microbaroms can routinely achieve Fstats of 10 or more, suggesting that they will often trigger the detector unless thresholds are placed on the energy of the signal.

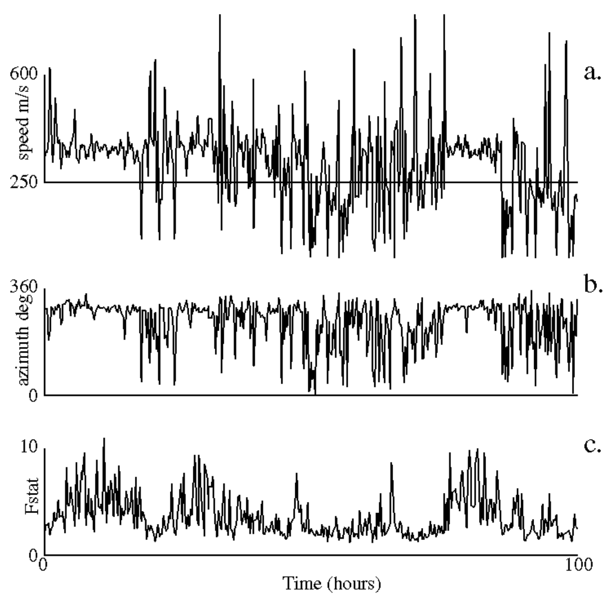
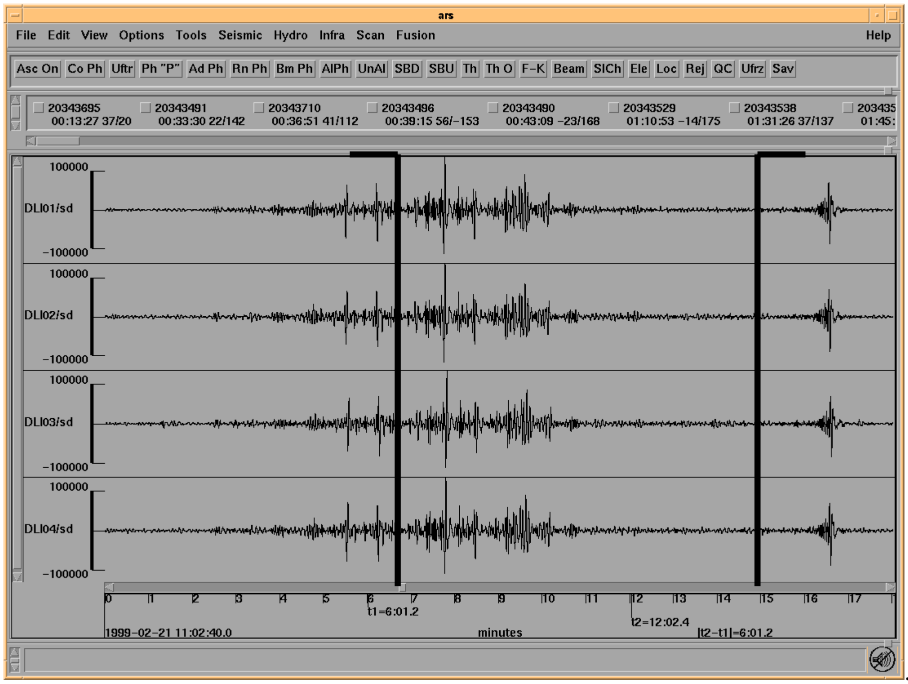


Figure 3: *speed, azimuth* and *fstat* for the 4 day period. Data filtered between 3 and 8 seconds.

A total of 42 man-made or naturally occurring signals with fstat > 2.0 were found to exist in the data and were excised in the subsequent analysis.

Signal Implantation

Signal implantation is always done so as to avoid the dominant microbarom direction. Typically, an arrival azimuth in the first quadrant, with azimuth less than 90degrees from north, is chosen. The signal is divided into three slowness regions with the intention of accommodating multipathing. An implanted signal is shown in Figure 4 with the three slowness regions indicated.



tropospheric stratospheric thermospheric

Figure 4: Example of implanted signal + backround data. Implant SNR = 25.0 . The three different phases have been indicated.

The signal is implanted according to the following prescription:

1. Assume there are $N = 2k$ points in the signal $\{S_1, \ldots, S_N\}$
2. Separate the signal into $N/2$ frequency pickets and calculate the power in each: $\{P_1, \ldots, P_{N/2}\}$
3. Call the total power T where $T = \sum_{i=1}^{N/2} P_i$
4. Sort the pickets into descending order of power: $\{U_1, \ldots, U_{N/2}\}$ and determine the index M at which 95% of the total power is obtained: $R = 0.95T = \sum_{i=1}^{M} U_i$
5. Extract the N-samples of background data where the signal is to be implanted, call these $\{X_1, \ldots, X_N\}$. Calculate the power in the $N/2$ pickets, call it $\{W_1, \ldots, W_{N/2}\}$, call $S = \sum_{i=1}^{N/2} W_i$
6. Sort the pickets into descending order of power: $\{V_1, \ldots, V_{N/2}\}$ and determine the 95% index K $Q = 0.95S = \sum_{i=1}^{K} V_i$

7. Specify the scale factor g as $g = \sqrt{\frac{Q}{R} SNR}$ where *SNR* is the desired implant SNR.
8. Create the new waveform as $Y_{J+i} = X_{J+\Delta+i} + gS_i$ where *J* is the insertion point and Δ is the delay.

PD

In specifying Probability of Detection, three different possible definitions were considered, viz:

1. 'Energy Packet' detection
2. 'Individual Phase' detection
3. 'Signal' detection

It is important to decide on an appropriate definition of PD as this definition can significantly alter the final arrangement of detector parameters. For example, it was found that long gap and LTA times strongly promote individual packet detection, but at the expense of detecting natural signals such as microbaroms.

Analyst inspection indicates that approximately 21 individual energy packets exist within the signal. Although it may be aesthetically pleasing to consider individual packet detection as a basis for PD, one must remember that an analyst will always inspect the signal, and whether two Energy Packets close together in time are detected together is not as significant as just one of the pair being detected. In addition, it is probably more appropriate to consider detecting individual phases (tropospheric, stratospheric and thermospheric) than just a single implanted signal. The signals of interest, as shown in Figure 1, can be at least 15 minutes in duration, and it may be possible for an analyst to simply miss one of the phases since it may not be in their analysis time period. The definition of PD used throughout this analysis, therefore, is the phase detection definition. With ninety-six implants, and three phases per implant, a PD can be determined for each phase and then for the signal as a whole.

FAR

False Alarm Rate controls detector performance. If infinite FAR were allowed, then the Detector would always be 'on' and a PD value of 1.0 would always be obtained. Conversely, if the FAR were zero, no false alarms would be tolerated and a PD value of 0.0 would always prevail; the detector would always be in the 'off' position. It is necessary, therefore, to establish definition of False Alarm Rate, and then settle on a reasonable value for FAR.

The general philosophy adopted here when defining False Alarm is that False Alarm Rate must be independent of the implantation strategy, i.e., False Alarms can only originate outside the implant region. By examining three features of each detection, namely azimuth, θ, speed |***s***|, time of arrival, and whether the detection is likely to be generated by microbaroms, it is possible to devise the following 'truth-table' for each detection. Here, θ indicates that the detection is, within a small error, coming from the implant azimuth; |***s***| indicates that the speed corresponds to one of the specified slownesses; time indicates that the detection occurs within an implant; and microbarom indicates that the detection is considered to be a microbarom. The θ designation and microbarom designation are mutually exclusive.

θ	T	F	F	T	F	F	F	F	T	T
|***s***|	T	T	F	F	F	F	T	T	F	T
time	T	T	T	T	F	T	T	F	F	F
microbarom	F	F	F	F	T	T	T	F	F	F

Genuine signals
Spatial aliasing
microbaroms
False Alarms

With this definition of FAR, it was decided that a FAR value of 30 per day would be acceptable.

Parameter Variation

The major parameters affecting Detector performance are listed in Table 1, along with a brief description of each parameter.

sta-time	Length in seconds of the Short Term Average window
gap-time	Length in seconds of the gap between the STA and LTA windows
lta-time	Length in seconds of the lagged Long Term Average Window
coherent-threshold	Threshold in the Primary Detect Space which the coherence has to achieve before a detection is allowed.
sta-lta-threshold	Threshold in the Primary Detect Space which the ratio of the *L1* norm of the STA window to that of the LTA window has to achieve before a detection is declared..
slowness_criterion	Radius around a given 'detection' in the slowness plane inside which all other detectio will be considered to be in the same cluster.
beam_recip_snr	Back-end coherence threshold in the Coincidence Detect Space that needs to be exceeded before a detection is declared.

Table 1: Detector parameters considered in the tuning exercise.

The tuning strategy decided on here was the following. Signals of varying SNR were implanted into the background channel data. A suite of DFX detection runs were performed in which a single parameter is varied until a peak in the PD versus parameter-value curve is achieved, -for the specified FAR. For some parameters, the curve obtained proved to be somewhat insensitive to changes in the parameter value. In these situations it was possible to minimize total microbarom count. Indeed, the microbarom count often proved to be quite sensitive to the particular choice of parameter value. The parameter is then assigned this value, which will be held constant for all future runs. The next parameter is then varied in the same manner, maintaining the same FAR.

An example, showing results obtained for the variation of the ***sta-lta-threshold*** parameter is shown in Figure 5.

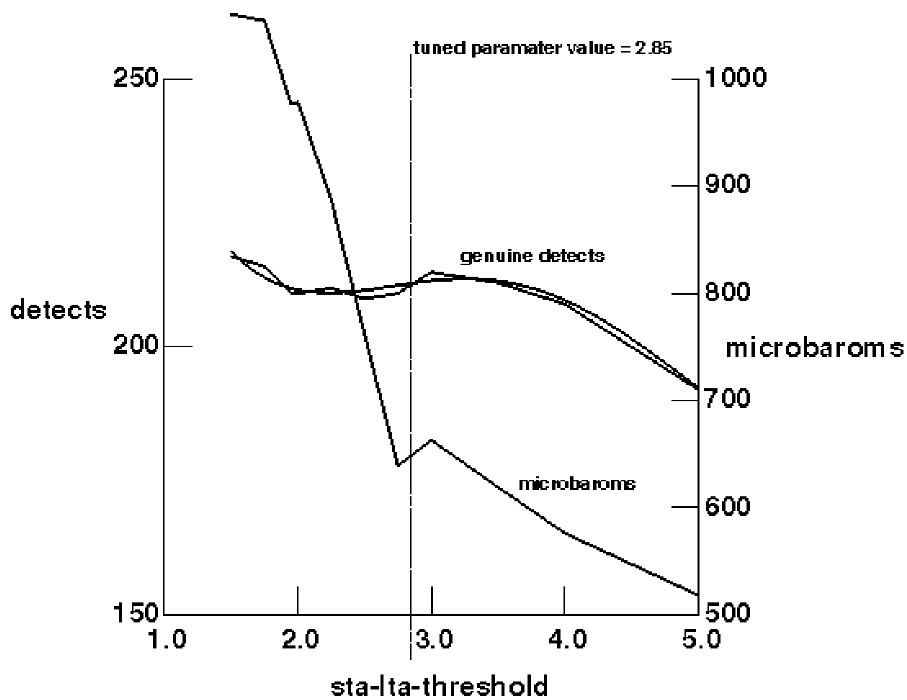


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Figure 5: Variation of detect count with sta-lta-threshold. A 4-th order polynomial interpolation is shown as well as the variations in microbarom detections.

In this case, the genuine detection count is observed to be weakly-dependent on the ***sta-lta-threshold*** parameter. Microbaroms, however, appear to be strongly-dependent on the choice of parameter and it is therefore prudent to choose the parameter value near the crest of the genuine detect curve and near the local minimum in the microbarom count.

Final values for the 7 parameters considered in this exercise are shown in Table 2.

sta-time	8
gap-time	120
lta-time	45
coherent-threshold	1.765
sta-lta-threshold	2.85
slowness_criterion	0.38
beam_recip_snr	1.5

Roc Curves

Determination of the ROC curves for this Detector is the final task in this project and are currently being generated.

CONCLUSIONS AND RECOMMENDATIONS

Detector tuning exercises of this kind need to be performed to establish optimal Detector performance for the signals of interest. To achieve this goal, it was found necessary to rigorously define concepts like ‘Probability of Detection’ and ‘False Alarm Rate’. With these definitions in place, and using synthetic signals that closely resemble the signals of interest, a tuning exercise has been performed that has allowed us to maximize the detection rate for the signals of interest, and reduce the detection rate for signals such as microbaroms that are not of interest. A recommendation must be that these exercise be expanded to include other representative signals, with different ambient noise conditions and geographic locations.

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Key Words: Infrasonic signal detection, ROC curves, False Alarm Rate, Probability of Detection, IMS infrasound array