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A Review paper on Infrasound event Detection & Localization

Vaibhav B. Tyagi[1], Shiv Sunder Lokesh[2], Abinet Tesfaye[3], Yordanos Kassa[4], Tasew Ababe[5]

Abstract— **There are certain events like Avalanche, breaking of rocks that emit infrasound signals. The infrasound waves generated by the events are coherent Acoustic waves that can be picks up by the acoustic infrasonic sensors, these infrasound signals after processing can be used to detect & localize such events. This information can be used to avoid losses of human life and property.**

Index Terms—**Infrasonic Sound (IS), Infrasound Source Localization (ISL), Direction of Arrival (DOA), Time Delay Estimation (TDE).**

I. Introduction

Infrasound is a sound that is lower than 20 cycles per second. This is sound that is just below the lower limit of the human sense of hearing. Due to its low frequency content, infrasound can travel over enormous distance as it experiences little attenuation. Infrasonic waves in the atmosphere are considered in the frequency range of 0.002 to 20 Hz, which travel with the speed of sound and have amplitudes in the order of 10−2Pa to 102Pa at the receiver, and travel for hundreds to thousands of kilometers. There exist a large number of sources of infrasound. The natural sources include wind and atmospheric turbulence, earthquakes and volcanic eruption, snow avalanches, waterfalls and breaking waves, animals etc. The artificial sources of infrasound includes air conditioning systems, wind energy turbines, gas turbine power stations, industrial facilities, vehicles, explosions, speaker systems, organ pipe, etc.

II. Infrasound signal detection techniques

A. Correlation Discrimination Technique

The maximum aggregated correlation coefficient (MACC) sequence [c] can be used to determine more than just the angle of arrival estimate. Different properties of the cross-correlation sequence can also be used to discriminate avalanches and explosions from noise. Since only avalanches, explosions, and a few types of interfering noise generate signals in the infrasound band, the cross-correlation sequence values will only increase when one of these signals is present. Consequently, the cross-correlation sequence can be the first step in determining whether or not a signal of interest is present in the recorded data. A threshold can be used to distinguish anything above the threshold as a signal, and anything below the threshold as not containing a signal. Using this same threshold, the time duration of the event can be calculated based on where the event crosses the threshold. Any peaks in the cross-correlation sequence besides the avalanche occur over a very short time period, and only the avalanche has a significant elevation in correlation coefficient. Increased cross-correlation values and time duration can be used for discriminating out different events.

B. Angle of Arrival Discrimination Technique

The angle of arrival sequence also has several useful properties that can be exploited for determining if any signals of interest are present in the data. After an event has crossed the cross-correlation sequence threshold, the angle of arrival sequence can be computed during that time duration. Since bombs and wind are stationary in nature, they should come from one angle with very little deviation from that angle. Since avalanches travel down the mountain, the angle of arrival should follow a range of values and not be stationary. This allows the standard deviation of the angle of arrival for an event to be used to determine whether or not it is an avalanche. Also, explosions during control work usually come from the top of the mountain, while avalanches are limited to the slide path. So the mean value of the angle of arrival sequence for the event can be used to determine the type of event.

III. Infrasound source localization

The process of determining the location of an acoustic source relative to some reference frame is known as acoustic source localization. The most common technique used for the localization of signal sources including avalanches, is to determine the time difference of recordings across different data-channels, by using the cross-correlation function [4]. The basic idea behind cross-correlation is to shift the data recordings in pairs of channels in time, and then perform a sum of the multiplications of the overlapping datasets to determine how related the two data sets are at each shift in time. Then the time shift, or lag, with the highest cross-correlation value corresponds to when the two signals are related the most. The array signal processing is based on the assumption that a signal is coherent at the different sensors, while noise does not show any correlation.

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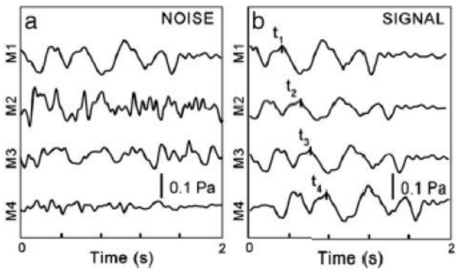

Figure1. Non-Coherent and Coherent Signal

If more than two sensors are available, then the time-delays obtained from all pairs of sensors can be used to improve the estimation of the direction of arrival of the signal. The different cross-correlation coefficients can be spatially aggregated together to determine an angle of arrival and overall position estimate for the entire system.

A. Generalized Cross Correlation Method

The acoustic sound source is localized with the help of time difference of arrival (TDOA) calculated using correlation of signals obtained from different acoustic sensors. Let‘s begin by examining previous research for estimating time difference of arrival known as generalized cross-correlation (GCC) methods. These are referred as "classical methods". With these methods, data from the two channels are transformed to the frequency domain to form the conjugate product *XY** (cross-spectrum). After appropriate weighting, an inverse discrete Fourier transform (IDFT) is performed and the peak of the resulting generalized cross-correlation function is located in the time domain.

Let m_i for i € [1, M] be the three dimensional vectors representing the spatial coordinates of the i^{th} microphone and "s" as the spatial coordinates of sound source. Consider that the source "s" is excited and the time difference of arrivals is measured. Letting ‗c‘ as the speed of sound in the acoustical medium (air) and || || is the Euclidean norm, the TDOA for a given pair of microphones and the source is defined as the time difference between the signals received by the two microphones.

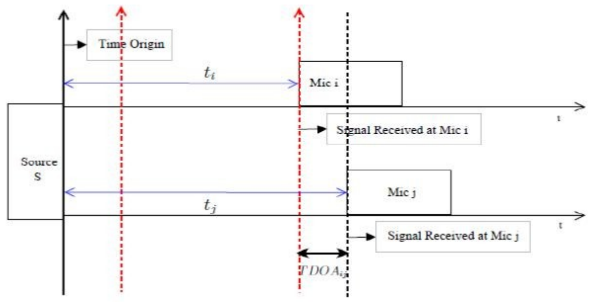

Figure 2. Schematic Depicting Time of Arrival & TDOA

Let $TDOA_{ij}$ be the TDOA between the i^{th} and j^{th} microphone when the source "s" is excited. It is given by

$$TDOA_{ij} = \frac{(\|m_i - s\| - \|m_j - s\|)}{c} \quad (1)$$

TDOA‘s are then converted to time delay estimations (TDE‘s) and path differences [5]. This is depicted in Figure2.

B. Time Delay Estimation

The most common method in TDE algorithms suitable for real-time operation of localization is the conventional generalized cross-correlation (GCC). In the problem of Time Delay Estimation (TDE) a signal is emitted from a source (e.g., infrasound is emitted from an avalanche) and is received at two spatially separated sensors. If *s1(t)* represents the original undistorted source and n1*(t)* and *n2(t)* represent sequences of uncorrelated, additive noise, then the signals received at two spatially separated sensors may be modeled as *x1(t) = s1(t) + n1(t) x2(t) = as1(t + D) + n2(t)* where D is the time delay between the two sensors. In the unknown source case, x1(t) and *x2(t)* and the ordinary cross correlation may be used to estimate the position and velocity of a moving source. The lag at which the cross-correlation function has its maximum is taken as the time delay between the two signals [6]. For the known source case, ordinary correlation involves using the original source and only one received signal to estimate the time it takes the signal to travel from the source to the receiver, i.e., *m(t)* = 0 in the model given above. In the absence of propagation distortion, this is matched filtering, which is the optimum linear method when the noise is white. Once the signal has been detected and the time delay D has been estimated, the time delay can be used to estimate the bearing angle *B* shown in Figure 3.

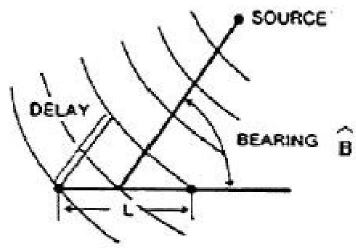

Figure3. Planner Model of Two Sensors for Bearing Estimation

The bearing estimate is given by the approximate rule

B^ = cos-1*(cD/L)* (2)

Where *c* is the speed of sound in water, *B* is the bearing estimate and *D* is the time delay estimate. It can be shown that *B* is the angle that the hyperbolic "line of position" makes with the axis of the receivers; hence the approximation for bearing estimate is increasingly accurate as the range to the acoustic source increases.

C. Triangulation

Triangulation is the process of determining the location of a point by measuring angles to it from known points at either end of a fixed baseline, rather than measuring distances to the point directly as been done in trilateration. The point can then be fixed as the third point of a triangle with one known side and two known angles. Basically, the configuration consists of two sensors observing an item. The projection centers of the sensors and the considered point on the object‘s surface define a spatial triangle. Within this triangle, the known distance between the sensors is the base *b*. By determining the angles between the projection rays of the sensors and the basis, the intersection point, and thus the 3D coordinates, is calculated from the triangular relations.

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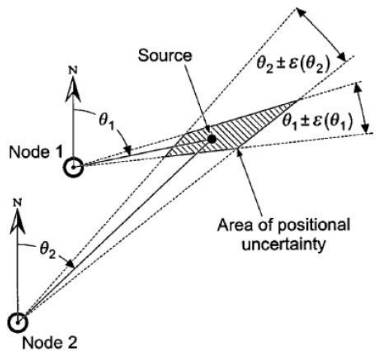

Figure4. Source Localization by Triangulation using Two Nodes.

Source Localization by Triangulation using two nodes Firure4. Shows the principle of Triangulation using two nodes. The source & the two nodes labeled 1 & 2 are located on the x-y plane at coordinates (Xs, Ys), (X_1, Y_1) & (X_2, Y_2) Respectively, with the Y axis pointing towards the north .The Bearing lines from the two nodes intersect to determine a unique source location [7].
Assuming line-of-sight propagation, the source position is given by

$$x_s = (y_s - y_1)\tan\theta_1 + x_1,$$

$$y_s = \frac{x_2 - x_1 + y_1 \tan\theta_1 - y_2 \tan\theta_2}{\tan\theta_1 - \tan\theta_2} \quad (3)$$

Where θ is the source bearing measured relative to the *y* axis at node *n* (*n*=1, 2), that is, with respect to north. The positional uncertainty of the source, represented by the shaded area in Figure4. Is determined by the uncertainties in the source bearings. The accuracy of the source position estimates is determined by the accuracy of the source bearing estimates. The difference in bearing estimation performance using different sensor pairs is attributed to the direction of the source relative to the orientation of the sensor pair axis coupled with various factors such as time-delay estimation errors. Though triangulation is fast method but it has certain disadvantages which include: (a) the increased amount of time needed in comparison to single strategies, (b) difficulty of dealing with the vast amount of data.

D. Time Difference of Arrival

Acoustic source present in the near-field can be localized with knowledge of the time difference of arrivals (TDOAs) measured with pairs of microphones. The speed of sound in the medium in which the acoustic source is present is assumed to be fixed and known. Most practical acoustic source localization schemes are based on TDOA estimation for the following reasons such as the systems are conceptually simple; they are reasonably effective in moderately reverberant environments. Moreover, their low computational complexity makes them well-suited to real-time implementation with several sensors.

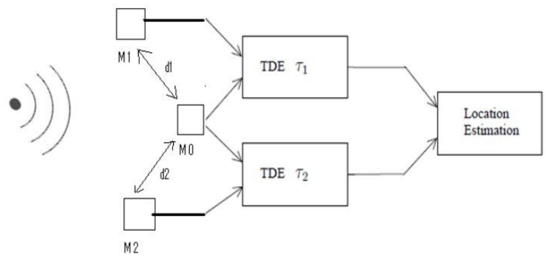

Figure5.Two Stage Algorithm for Acoustic Source Localization.

The first stage involves estimation of the TDOA between receivers through the use of time delay estimation techniques. The estimated TDOA‘s are then transformed into range difference measurements between sensors, resulting in a set of nonlinear hyperbolic range difference equations. The second stage utilizes efficient algorithms to produce an unambiguous solution to these nonlinear hyperbolic equations. The solution produced by these algorithms result in the estimated position location of the source.

E. Multilateration

Multilateration is a common technique in radio navigation systems, where it is known as hyperbolic navigation. It is based on range difference between the different sensors which is calculated in turn from TDOA measurements; but unlike the measurements of absolute distance or angle, measuring the difference in distances results in an infinite number of locations that satisfy the obtained measurement. When these possible locations are plotted, they form a hyperbolic curve. The intersection of several hyperbolic curves gives the exact location of source. These systems are relatively easy to construct as there is no need for synchronization between transmitter and receivers.

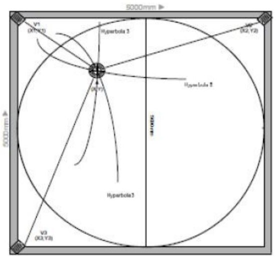

Figure6. Acoustic Source Localization using Multilateration.

Multilateration is, in general, far more accurate for locating an object than sparse approaches such as triangulation or trilateration , where with planar problems just three distances are known and computed. Due to lesser complexity, ease of implementation and more precise and accurate results, multilateration technique has been considered as the most apt for the purpose of localization in this project of avalanche detection and localization.

IV. CONCLUSION

Avalanche is a moving source of infrasonic wave. It generates a coherent acoustic wave that can be picked-up by the acoustic infrasound sensors. Hence by setting up Infrasound localization system in the infrasonic prone areas,

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the location and time of occurrence of avalanche activity can be estimated. The future scope of the study is to carry out Design and Implementation of Architecture for Prototype Infrasound Detection and Localization System.

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Vaibhav B. Tyagi, is Pursuing PhD (Signal Processing), earlier he completed his M. Tech (Honors) in Electronics from IIT ROORKEE, B. Tech (Honors) from UPTU & Diploma in Engineering from Govt. Polytechnique College, Alwar, He has published 5 International Journal papers and presented 3 Papers in International conference. He is having more than 7 years teaching experience (National & International) both on graduate and Post Graduate levels in various reputed Technical universities. .His research areas include Acoustic Localization, Target classification, Beam Forming, Sensor Array Processing etc.
SS Lokesh, is working as a Professor in Gyan Vihar University, Jaipur.
Abinet Tesfaye, Completed his M.Sc & B.Sc, working as HOD Electrical Engineering MeU, Africa. Research area DSP & Power Drives.
Yordanos kassa, Completed his M.Sc & B.Sc, working as DEAN Electrical Engineering MeU, Africa. . Research area DSP & Electrical Machines
Tasew Ababe, completed his B.Sc, working as Lecture Department of Electrical Engineering MeU, Africa. Research area Digital Electronics.

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