ENERGY – INFORMATION TRILATERATION METHOD OF ACOUSTIC LOCATION FOR DEFECTOSCOPY OF WIDE – SCALE DISTRIBUTED INDUSTRIAL STRUCTURES

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Introduction

Increasing of accuracy of localization of zones where the acoustic waves are generated as a result of various emergency situations occurred in wide-scale distributed industrial structures is highly important and actual task.

There is a special subclass of wide-scale industrial distributed structures, where the emergency situation, occurred due to any non-clear malfunction in operation of whole system leads to forming of the hidden zone of acoustic waves emission in some frequency band. As an example of possible objects where such events may occur the underground high-pressure pipelines, high energy generating machine halls, the network of generating field sensors, the wind energy generators installed as a group, the temporal development of rest deformations in wide-scale industrial constructions etc. may be considered.

The abovementioned task is traditionally solved using triangulation or trilateration methods. In common case we can stress out following shortages of these methods:

1. In triangulation method the acoustic wave's propagation speed and time of arrival of wavefront should be determined with high accuracy. But as it is noted in [1], both the temperature and humidity of media render a significant effect on acoustic waves and non-homogeneity of temperature and humidity in the area can lead to forming of methodic error of calculation.

2. In trilateration method two modifications can be applied:

- signal strength measurements technique:
- measurement of distance between the microphone and object.

While the realization of the first techniques requires implementation of iterative procedures, the second one demands high-accuracy distance measurements which would necessitate application of non-acoustic methods for accurate distance measurements.

3. In both methods the accuracy of localization depends on accuracy of implementation of needed geometrical procedures.

BRIEF REVIEW OF RELATING APPLICATIONS OF ACOUSTIC LOCATION METHOD

An original method of triangulating of point sources using unidirectional sensors is described in [2].The techniques of utilization of phased arrays to determine the bearing angle of waves sources is used in this work. The interference pattern created between two or more sensors and the time-delay between them of known distance is used to calculate difference of amount of waves received by two sensors from a source..

To solve these problems, an energy of signal measurements is suggested which uses the radiative transfer of energy from the source in conjunction with the spherical pick-up pattern of sensors to carry out triangulation.

As it was mentioned above, using the measuring of signal strength is widely used in solution some location problems by way of trilateration method. In the work [3] the method of local signal strength gradient is described,

In this trilateration method the distances from the signal source as far as a measurement points are estimated and combined to infer the location of object. The path losses from transmitter to receiver are defined as a function of distance.

The gradient calculation is based on the concept that the signal strength indirectly reflects the coming signals direction.

The location of grouped object is considered in the work [4], where a distributed location network derives the geographic constraints and uses them to carry out high accuracy location. It sets up relative geographic constraints among the network members at the basis of network connectivity and solvs the system with the aid of position information provided by several landmarks.

In another task of location of generated devices in indoor environment a weighted center of mass based trilateration approach was used [5].

The suggested approach consists of two phases: (1) determination of distance using signal strength of all access points as received by the mobile device, (2) Determination the most probable location of object using coordinates of access points and calculated distances of the object from those points. The suggested algorithm guarantee location of mobile object in indoor environment where the configuration of access points is not fixed and the movements in signal attenuating environment is unpredictable.

More complicated algorithm to estimate the direction of arrival of acoustic signals, named as Dominant Frequency Selection (DFSE) algorithm is suggested in work [6] where the direction of arrival estimation using microphone arrays is determined to use the phase information present in signals from spatially separated microphones. DFSE uses the phase difference between the Fourier transformed signals to estimate the direction of arrival (DOA) and is implemented using a three-element 'L' formed microphone array, linear one, and planar type 16- microphone array. The method is based on locating of maximum value from Fourier transformed signals and thereby deriving the location information by solving the set of non-linear least squares equations.

As it is noted in the work [7], target localization using acoustic signal with tiny wireless devices is a particularly difficult task due to the amount of signal processing and computation involved. A cluster-based architecture was developed to address the limitations of the tiny sensing devices. To achieve effective utilization of the scarce wireless bandwidth, a quality-driven paradigm to suppress redundant information and resolve contention is suggested. One instance of used approach is implemented in the acoustic tracking system, where the quality of the tracking reports can be assessed numerically.

There is a specific military direction of acoustic location which is called as sound ranging the aim of which is localization of gun firing. The sound-ranging problem is solved in [8] using improved time-delay estimation methods to refine the source position estimates. The time difference for the acoustic wavefront to arrive at the spatially separated sensors is estimated by cross correlating the digitized outputs of the sensors. The time-delay estimate is used to calculate the source bearing, and the source position is cross fixed by triangulation using the bearing from two widely separated receiving nodes.

There is a wide sphere of industrial application of acoustic location. As it is described in the work [9] low withstand voltage capability was found during high-potential testing of an electrical system consisting of a large superconducting coil and the equipment connected as it was installed in the International Fusion Superconducting Magnet Test Facility (IFSMTF).

An acoustic emission (AE) measurement system was developed to determine the location of breakdowns in large coils after installation in IFSMTF. Using triangulation with AE sensors, the system measures the difference in time-of-arrival of transient waveforms caused by the direct current voltage discharge. The system was calibrated on a stainless steel surface representing the coil case, and its accuracy was found to be better than 5cm.

Another case on utilization of acoustic location for industrial purposes is described in [10]. As it is stated in [10], the measurement of partial discharges (PD) is a non-destructive and sensitive diagnostic tool for the condition assessment of insulating systems. Two major tasks of PD measurements may be distinguished, (i) PD detection, hence providing evidence and the type of the PD and (ii) the location of the PD.

Here the possibility to geometrically localize the flaw, by means of arrival times of acoustic PD signals, gets an extremely interesting option. The averaging of acoustic PD signals helps to enhance the acoustic sensitivity. The acoustic detection limit is lowered significantly and the determination of the arrival times is made possible for weaker PD. Supplementary steps, likes automatic objective arrival time determination or additional wavelet-based de-noising further improve the overall location accuracy. A new location approach works with pseudo-times and allows for the use of robust direct solvers instead of the previously used iterative algorithms.

One of military applications of acoustic location is the development and testing of precision ballistic and guided weapons which require the occasional discharge of those weapons. For newer weapons with greater operational envelopes, this often requires testing over very large areas[11].

Offshore ranges pose a challenge of determining the location of impact of ballistic and guided weapons. At sea an impact can only be observed at the moment of occurrence. This observation must also account for absolute position, which is difficult in a marine surface environment without any permanent physical landmarks.

The Tactical Acoustic Realtime Geolocation and Training (TARGT) system, developed by Trident Research LLC, is a distributed floating array that provides an accurate and low cost underwater acoustic method for locating offshore weapon impacts in near-realtime, using a time difference of arrival algorithm.

The major conclusion from above brief review is that the major weak side of triangulation method is necessity to determine differences of time of arrival of wavefront, while in trilateration method the major problem is carrying out of iterative procedure of location.

SUGGESTED ENERGY-INFORMATION TRILATERATION METHOD

An interesting application of trilateration method named as iterative circles method was developed in [12, 13]. The physical basis of the circles method is as follows. As it is known[1], the amplitude of the acoustic pressure at the distance x can be calculated using following formula

$$P = P_0 e^{-mx}, \tag{1}$$

где P_0 - the amplitude of acoustic pressure at the source; P - the measured value of acoustic pressure at the distance x; m - doubled coefficient of common attenuation[1].

The method is based on drawing of circles using the equation (1) which make it possible to find out x as

$$x = \frac{1}{m} \ln \frac{P_0}{P} = \frac{1}{m} \ln P_0 - \frac{1}{m} \ln P = a - \frac{1}{m} \ln P, \tag{2}$$

where

$$a = \frac{1}{m} \ln P_0 .$$

It is obvious, that upon fixed values of temperature and humidity we get $a = const$. In this case, taking into consideration equation (2) upon utilization of three receiving microphones we can obtain following system of equations

$$x_1 + \frac{1}{m} \ln P_1 = a, \tag{3.1}$$

$$x_2 + \frac{1}{m} \ln P_2 = a, \tag{3.2}$$

$$x_3 + \frac{1}{m} \ln P_3 = a. \tag{3.3}$$

Assume, that the parameter m is known, but a is unknown.

In this case the location procedure does contain following steps:

1.1. Installation of microphones M_1, M_2, M_3 (figure 1).

1.2. Carrying out measurements of P_1, P_2 and P_3.

1.3. The most possible value of parameter a is used for calculation.

1.4. The geometrical constructions are to be carried out as follows: The place of installment of the microphone M_i is to be selected as a center of i-th circle, the radius of which is equal to $a - \frac{1}{m} \ln P_i$.

1.5. The triangular $S_1 S_2 S_3$ formed at the place of crossing of circles is to be considered as searched for zone of generation of acoustic waves.

1.6. If the square of triangular $S_1 S_2 S_3$ become too large, all above procedures should be repeated iteratively preliminary decreasing the radius of the circles.

1.7. Whole geometric procedure of development of triangular resulting from crossing of circles should be repeated till transforming of triangular $S_1 S_2 S_3$ into point O. But as it is clear from abovementioned, if the power of the source is unknown the method of circles doesn't allow to determine instantly the zone of emergency generation of acoustic waves and require the carrying out of iterations to reach the searched place.

To remove the abovementioned shortage of the circles method we suggest to use as a basis the distance as far as the maximum informative zone of generation of acoustic waves. This zone can be found using the method of information location [14, 15]. Here we briefly remind the matter of this method. In this method we assume, that the acoustic waves as random type signals are equally distributed over and generated from the zone of emission.

These signals are received by receivers $A_i, i = \overline{1,3}$. In this task the criterion of optimization is obtaining the maximum amount of total information received by these receivers, which mean that the maximum amount of total information would be generated from the found emission zone. The information criterion of optimality can be written as

$$F = \sum_{i=1}^{3} \left[\frac{T_i}{\Delta T} \log_2 \left(\psi_0 + \psi'_L L + 1 \right) + \lambda \left(\psi_0 + \psi'_L L + 1 \right) \right], \qquad (4)$$

where ΔT - step of discretization of siqnals at the input of receivers $A_i, i = \overline{1,3}$. T_i - duration of received signal at the input of receiver A_i; ψ_0- signal/noise ratio at $L = 0$; $\psi'_L = \frac{d\psi}{dL}$; λ – Lagrange multiplier.

In order to form the functional of unconditional optimization the following limitation condition is adopted

$$\sum_{l=1}^{3} \left(\psi_0 + \psi'_L L + 1 \right) = C = const . \qquad (5)$$

The solution of optimization task (4) using the Euler's rule is obtained as follows

$$L_i = \frac{\psi_0 + 1}{\left| \psi'_L \right|} - \frac{T_i \cdot C}{T_{max} \cdot \left| \psi'_L \right|} . \qquad (6)$$

Upon $\psi_0 >> 1$ from the formula (6) we can derive following equation

$$\frac{L_i}{L_{max}} + \frac{\alpha \cdot T_i}{T_{max}} = 1, \qquad (7)$$

where $\alpha = const$.

Thus, the algorithm for calculation of position on maximum informative zone in this method is formulated as following:

1. The values of parameters $\psi_0; \psi_L^{'}; L_{\max}; T_{\max}; \alpha$ are to be given.

2. Taking into consideration the real conditions, the values of L_i, $i = \overline{1,3}$, and, the values of T_i using the equation (7) should be determined. Therefore, the set of pairs (L_i, L_i) $\{(L_1,T_1);(L_2,T_2);(L_3,T_3)\}$ is to be formed.

3. The rotation of pairs (L_i, T_i) on unmovable receivers A_i, $i = \overline{1,3}$ is to be carried out. In each step of rotation the value of following sum is to be calculated.

$$F_1 = \sum_{i=1}^{3}\left[\frac{T_i}{\Delta T} log_2\left(\psi_0 + \psi_L^{'} + 1\right)\right]. \qquad (8)$$

4. Such step of rotation procedure should be chosen, upon which the sum (8) would reach maximum value.

5. Taking into consideration the values $\{L_i\}$, $i = \overline{1,3}$, the geometrical construction of the zone is to be carried out by drawing the circles with radius L_i from the points of placements A_i, $i = \overline{1,3}$ (figure 2).

MODEL RESEARCH OF COMBINATION OF INFORMATION LOCATION METHOD WITH TRILATERATION METHOD

After calculation of $\{L_i\}$, $i = \overline{1,3}$, which determine the position of maximum informative zone, the location of this zone should be related with current intermediate zone found in first iteration of trilateration method. Effect of such a combination is a possible decrease of area of zone where the next iteration should be carried out. The modeling procedure could be based on following considerations.

The following equalities are to be accepted

$$\begin{aligned} x_1 &= L_1, \\ x_2 &= L_2. \end{aligned} \qquad (9)$$

Taking into consideration the equations (3) and (9) the following system of equations is to be composed

$$L_1 + \frac{1}{m} \ln P_1 = a,$$
$$L_2 + \frac{1}{m} \ln P_2 = a. \qquad (10)$$

The system of equations (10) is to be solved in regard of m and a. By the help of found values of m and a, using the equation (3.3) one can calculate the value of x_3.

Apparently, the calculated values of x_3 and L_3 may be related as $x_3 > L_3$ or $x_3 \leq L_3$. The case $x_3 < L_3$ is shown in figure 2.

In this case the formed zone of possible emissions $O_4O_2O_5$ is wider than the maximum informative zone $O_1O_2O_3$. In order to guarantee the beginning of iteration process namely from zone $O_1O_2O_3$, the operational point for beginning of the iteration procedure should be taken closely near to point O_2, crossing point of L_1 and L_2.

Conclusion

Thus, the suggested method of combination of trilateration method and method of information location make it possible to decrease the number of iteration procedure steps in trilateration method, which can increase of high-speed operational capability.

It is shown, that the known trilateration method used for location purposes, requires carrying on out of multiple iteration procedures, which doesn't allow quick determination of emergency zone of acoustic emission.

In order to increase the quick – operational capability of trilateration m method, it is suggested to decrease the number of steps of iteration procedure by way of initial utilization of maximum informative zone, determined by method of information location.

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Summary

Energetic-information method for acoustic defectoscopy of wide-scale distributed industrial structures

It is noted, that the known trilateration method of location requires the carrying out of multiple iteration procedures, which doesn't allow to define operatively the place of generation of emergency acoustic waves.

In order to increase quickness of realization of location using the trilateration method it is suggested to combine it with the method of information location to determine the maximum informative zone of generation and to speed-up the process of localizations.

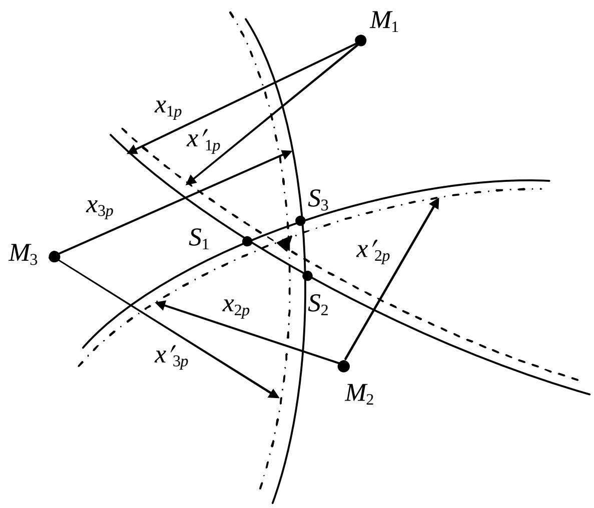

Figure. 1. Iteration procedure of location using the trilateration method.

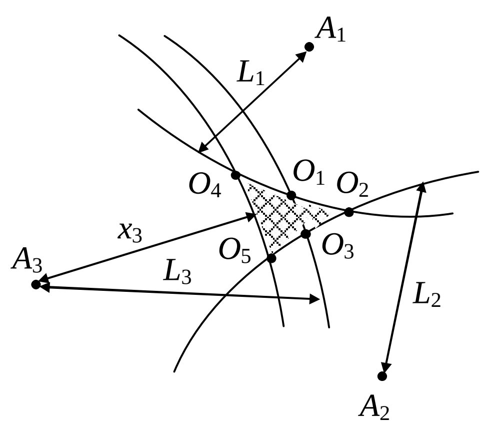

Figure. 2. Modelled combined procedure of location of acoustic waves generation zone.