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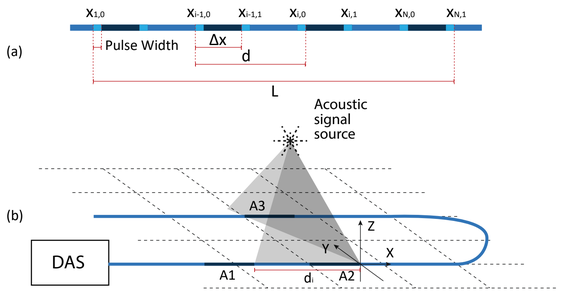
Algorithms for Determining the Location of an Intruder Using DAS in Space

Distributed Acoustic source localization algorythm based on the array signal processing method

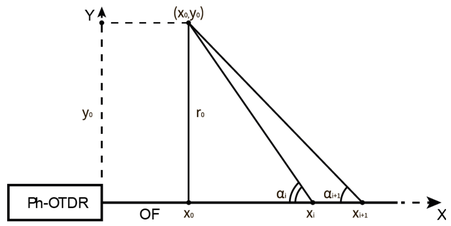


Model of a distributed array of sensors (a) and an equivalent array of sensors (b).

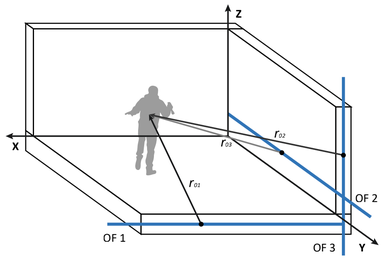
$$\Delta x = x_{i,1} - x_{i,0} \qquad d_i = x_{i,0} - x_{i-1,0} \qquad L = x_{N,1} - x_{1,0}$$

The estimation of the spatial spectrum is used and the function of the spatial spectrum P_{MUSIC} (classical multiple signal classification - MUSIC) is calculated

Method for determining the location of an intruder using DAS based on the algorithm of simple triangulation



Estimation of the shortest distance from the OF to the source of acoustic impact.



Determining the location of an intruder in 3D space.

$$\alpha_i = \arccos\left(\frac{\Delta\theta_i}{k\cdot\Delta x}\right) \qquad x_{0i} = \frac{x_{i+1}tg(\alpha_{i+1}) - x_i tg(\alpha_i)}{tg(\alpha_{i+1}) - tg(\alpha_i)}$$

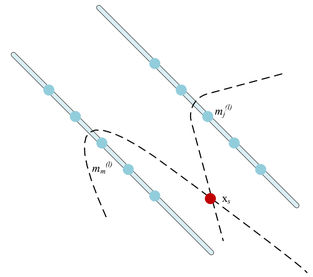
$$r_{0i} = \left|x_{i+1} - x_0\right|\cdot tg\alpha_i$$

$$r_0 = \sqrt{z_0^2 + x_0^2 + y_0^2} \qquad \Delta\varphi = \varphi_{i-1} - \varphi_i < 2\pi,\ k\Delta x < 2\pi,$$

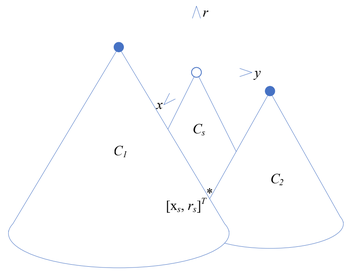
$$s_i(t) = \int_{x_{i,0}}^{x_{i,1}} \eta(x)\cdot\varepsilon(x,t)dx$$

$$P_C(t, x_i) = P_0 \exp(j\omega t)\int_{x_{i,0}}^{x_{i,1}} \frac{\eta(x)}{r}\exp(-jkr)dx.$$

Algorithm for determining the location of an intruder using time difference of arrival systems built on the DAS



Determining the location of the sound source at the intersection of hyperbolas obtained from TDOAs.



Determination of the sound source in the spatio-temporal reference system.

$$\alpha_{ij}^{(m)}x^2 + b_{ij}^{(m)}xy + c_{ij}^{(m)}y^2 + d_{ij}^{(m)}x + e_{ij}^{(m)}y + f_{ij}^{(m)} = 0$$

$$\varepsilon_{ij}^{(m)}(\mathrm{x}) = \mathrm{v}_{ij}^{(m)}(\alpha_{ij}^{(m)}x^2 + b_{ij}^{(m)}xy + c_{ij}^{(m)}y^2 + d_{ij}^{(m)}x + e_{ij}^{(m)}y + f_{ij}^{(m)}),\quad \mathrm{v}_{ij}^{(m)} = 1$$

for all TDOAs, which were found to be reliable, and 0 otherwise.

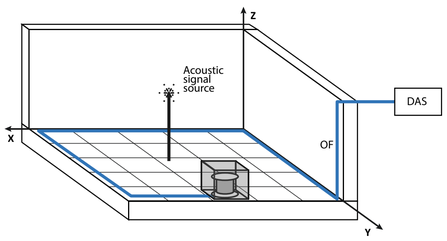
$$J_{HYP}^{(TDOA)}(\mathrm{x}) = \varepsilon(\mathrm{x})^T\varepsilon(\mathrm{x})$$

$$\|\mathrm{x}_s\| - \hat{r}_j = \|\mathrm{x}_s - m_j\|,\quad \hat{r}_j = c\hat{\tau}_j$$

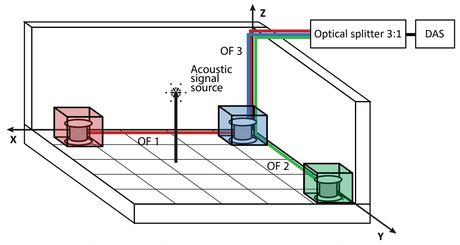
$$r = \|\mathrm{x}_s - \mathrm{x}\| - \|\mathrm{x}_s\|$$

$$r_s = -\|\mathrm{x}_s\|$$

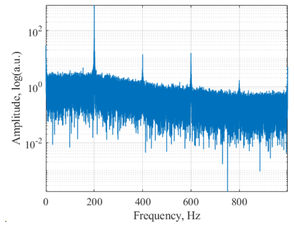
Simulation of data obtained and algoritms comparison



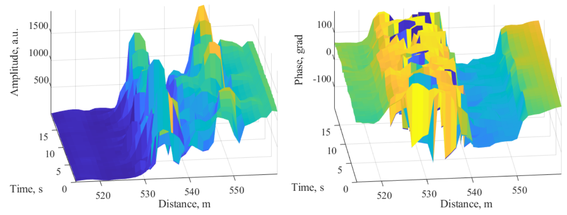
Test configuration with one fiber optic cable arranged in three planes.



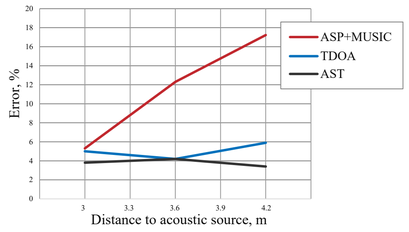
Test configuration with three fiber optic cables arranged in three planes.



Spectral characteristic of the acoustic signal.



Amplitude (a) and phase (b) distribution on the fiber section in a configuration with a single optical cable.



Dependence of the source localization error on the distance to the sound source.

Despite the approximately equal error levels of the TDOA and AST methods, the AST method is most preferable, due to the more voluminous and more time-consuming calculations for TDOA. In turn, the ASP method shows a low error rate when the optical fiber is wound on the resonator structure, thereby reducing the calibration length of the DAS. It should be noted, that such configurations are not found in real operational conditions. The AST method requires further study and optimization of the mathematical model. A low-frequency signal has a greater effect on the DAS, but it has a tangible effect on all surrounding objects and structures leading to an increased proportion of parasitic influences on various sensor points.

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