UNCONVENTIONAL TECHNIQUES OF POSITIONING

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Abstract: *In this article are presented some positioning techniques used in other fields of work than the terrestrial measurements, areas for which required precision at positioning is not so restrictive as in the case of our field. With the unprecedented growth of technology in the last period and the progress made in the implementation of new systems in the field of infrared, ultrasonic and radio opportunity arises to integrate these technologies into the complementary positioning systems which track the cover produced by impossibility to use GPS systems in areas with satellite obstructioned signals.*

Keywords: *acoustic, syncronization, angle of arrival, sound mapping.*

By the point of wiew of their topology, the positioning systems can be divided in two categories depending on where the system components that allow getting data and those which aim to process the data received to determine the position of the followed device are located [1][2]. The "direct" system allow both acquisition and signal processing received from transmitters as well as automatic calculation of their position. These systems are based on network services in which signals transmitted by the mobile device are retrieved and processed by the reference stations integrated in a network, where, each station occupies a known position. The "indirect" system are systems in which the signals are picked up by one of system devices, and their processing is performed by the other device.

The most common systems for determining the position in covered areas are the infrared systems, ultrasonic systems, and radio positioning systems.

Infrared devices are cheap and easy to get, and so are often used for indoor positioning. The signals will not travel through walls, unlike radio signals that can penetrate the obstacle found between transmitter and receiver. This technology is inexpensive but the accuracy of positioning is quite low in comparison with systems based on other technologies.

Ultrasonic multilateration systems determine the positions of objects by measuring distances between ultrasound sources and detectors. These systems rely on measurements of the time taken for ultrasound to travel between sources and detectors and the distance measurement methods are based on a knowledge of the speed of ultrasound in air, which is around 340m/s, so units with microsecond resolution are sufficient to measure distances with sub-centimetre accuracy and so the electronic complexity of the systems is low.

Radio-based positioning systems are frequently used because the signals they use can pass through solid objects. Radio systems are used in positioning both in outdoor environments, as well as in indoor environments, signal reflections from objects are problematic. The main components that determine the resolution attainable in measuring distances through wireless technology are: signal parameters, the characteristics of the system used, and the physical and electromagnetic environment through which the signal propagates. Achieving high resolution in determining distances requires the use of large band-width systems, a high energy in order to obtain a signal / noise ratio favorable to the use of high-frequency oscillators. Positioning accuracy based on determining the time passed between transmitter and receiver signal depends largely on the accuracy with which syncs the clock receiver transmitters installed in known positions. Since the accuracy of the determination of the time passed between the transmitter and the receiver signal increases with an increase in the transmission bandwidth and, if the phase measurement accuracy of the determination of the time covered by the signal is enhanced by filtration. Reduction of the bandwidth leads to an increase in the time of measurement, while the use of larger tape width results in the signal / noise ratio [3].

Another possibility for unconventional positioning, in the geodetic engineering is the position of noise sources using acoustic systems. Concept of "mapping sound" refers to the detection of noise with the help of a system for determining the moment of arrival of the signal at each of microphone matrix receiver. Data taken simultaneously at all matrix microphones are recorded and transmitted computing unit to compensate for delays due to differences in distance from each microphone to the point of origin represented by the physical center of the antenna receiver. After time synchronization, sounds can be processed to determine the direction of signal of maximum sound pressure [4].

Since the distance between source and each microphone is different, appears a delay in the phase of the received signal who can be determined by the timing of receiving sensors, and data can be used to determine the angle of incidence of the received signal and the position of the source in its own coordinate system. This requires the system to be equipped with acquisition boards allowing very precise synchronization of received signals.

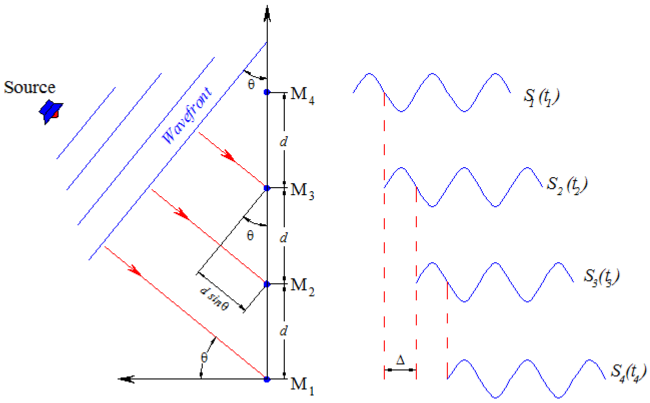


Fig.1: Phase delay of the signals at the four sensors

The signal processing can be done with Noise Inspector software designed for fast and accurate localization of noise sources. The processing methods used bz this software to locate the noise sources under static or dynamic regime, both environments indoor and outside. For signal processing are used specific methods to determine signal parameters such as Beamforming, Orthogonal Beamforming, CleanSC, MUSIC, Capon, Damas. The software allow advanced analysis to determine the level of noise and power spectrum, which is based on frequency response signals after filtering and after signal processing can be done in the field of time-frequency analysis. The most commonly used spatial methods for determination the direction of incidence of the received signal are Capon, Beamforming and ESPRIT.

The Capon Algorithm involves the use of a band-pass filter as narrow on a frequency ω, which is used to determine the spectral components of the signal. The angle of incidence of the received signal is determined based on the correlation matrix that describes the dependence between signals received from individual sensors receiver, and is given the power spectrum peaks offered by relationship spectrum Capon, which has the form:

$$\hat{P}_{Capon}(\omega) = \frac{N}{e^H(\omega)\hat{R}^{-1}e(\omega)} \quad (1)$$

The MUSIC algorithm (Multiple Signal Classification) starts from a system in which incoming waves are linear combinations between incident wave fronts and noise [5]:

$$\begin{bmatrix} X_1 \\ X_2 \\ \dots \\ X_M \end{bmatrix} = [a(\Theta_1)\ a(\Theta_2)\ \dots\ a(\Theta_D)] \begin{bmatrix} F_1 \\ F_2 \\ \dots \\ F_D \end{bmatrix} + \begin{bmatrix} W_1 \\ W_2 \\ \dots \\ W_M \end{bmatrix} \quad (2)$$

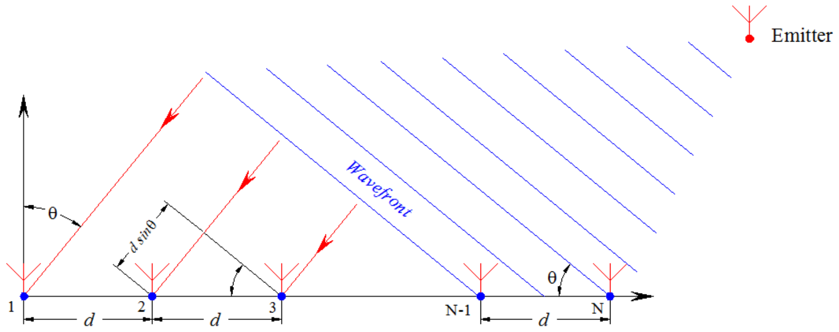


Fig. 2: Angle of arrival of the wave fronts

Considering a set of *M* sorting receptor sensors in the form of a linear arrangement of equal mutual distance, by which arrive *k* narrowband plane waves from different angles i, from transmitters that transmit on the same frequency, signal can be written as:

$$s_i(t) = u_i(t)e^{j\left(2\pi f_0 t + \varphi_i(t)\right)} \quad (3)$$

The covariance matrix has the form:

$$R_S = E\begin{bmatrix} s_1(t)s_1(t)^H & s_1(t)s_2(t)^H & \dots & s_1(t)s_p(t)^H \\ s_2(t)s_1(t)^H & s_2(t)s_2(t)^H & \dots & s_2(t)s_p(t)^H \\ \dots & \dots & \dots & \dots \\ s_p(t)s_1(t)^H & \dots & \dots & s_p(t)s_p(t)^H \end{bmatrix} \quad (4)$$

MUSIC spectrum is defined by a relationship as shown below, in which the maximum value of the report corresponding to the angle of incidence of the received signal:

$$P_{MUSIC}(\Theta) = \frac{1}{A(\Theta)^H \cdot \hat{U}_n \cdot \hat{U}_n^H \cdot A(\Theta)} \quad (5)$$

The ESPRIT algorithm (Estimation of Signal Parameters by Rotational Invariance Techniques) allowed the estimation of direction of arrival of the received signal with the help of irregular arrangement of sensors receiver. The mathematical model of the algorithm based on iterative interpolation of data in order to estimate the direction of arrival of the received signal and based on the use of pairs of sensors, with respect to the condition that the number of sensor pairs to be higher than the number of sources of emission.

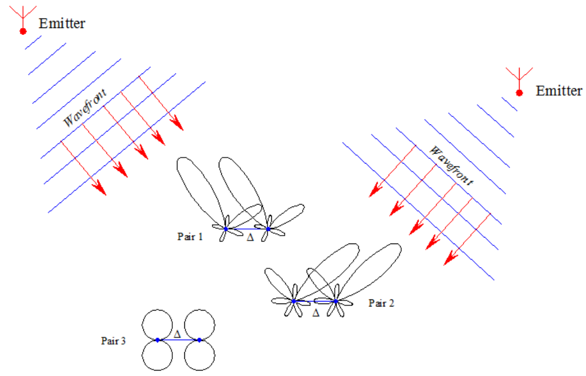


Fig. 3: Pair of sensors in a random arrangement

The spatial resolution of the sound location are the capacity of the system separation system to resolve two separate sound sources from each other. The higher the spatial resolution, the closer the sound sources can be to each other and still register as two separate sound sources. The resolution of the system is strongly influenced by the distance between the sound source and the receiver as well as the size and shape of the array of sensors and is given by [6]:

$$R = \frac{D \cdot \lambda}{A} \qquad (6)$$

R – spatial resolution;
D – distance between emitter and receiver;
A – diameter of the array;
λ – sound vavelenght

The sensors are designed to transform the system pressure oscillations into electrical signals that can be recorded and analyzed to provide information about the source of noise. They convert sound energy into electrical energy and are designed to allow the acquisition and processing of a wide range of amplitudes and frequencies. For correct sensor type is taken into account a number of features such as the dynamic response, frequency response, the type of polarization sensitivity required temperature range in which the application. A very important aspect is the way the sensors are attached to the receiver. Using arrays of sensors in a circular shape offers good accuracy where the distance between transmitter and receiver is unknown, but the low dynamic range instead a spiral arrangement gives better results and highest performance are offered systems with large number of sensors and random place that are characterized by a high dynamic range. Spatial resolution increases as the matrix size is larger receiver.

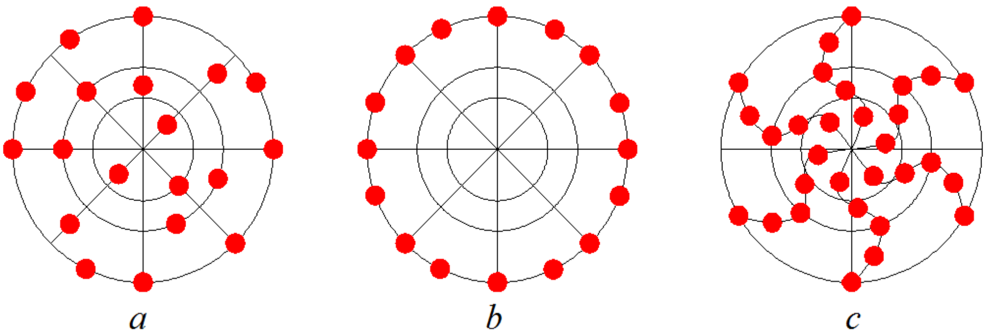


Fig. 4: The three main configurations for microphone arrays used in acoustic beamforming random *(a)*, ring *(b)* and spiral *(c)*

Case Study

Measurements presented in the case study were carried out at the company CAE Software&Systems subsidiary of the company CAE Engineering und Service GmbH, from Germany. Data acquisition was made with CAE „Spider-Array", equipped with GRAS 40PH „low-cost" sensors designed for sound mapping systems. These sensors have a wide range of frequency reaching 20 kHz and a dinamic range by 135 db. Each sensors is caracterized by a high senzitivity by 50 mV/Pa at 250Hz and a impedance lower than 50 Ω.

Noise source was 4 KHz produced by a cell phone, placed at a distance of 5 m from the receiving system and data aquisition was made for a time of 12,5 seconds. After retrieving the records, the software allows to view records in the chart for time-frequency analysis of the sound pressure. In order to perform an analysis of the results, data were taken at three different rates of frequency 1.6 GHz, 4 GHz and 10 GHz. For each of these frequencies, on the different recordings were applied post-processing algorithms in order to identify the accuracy of determining the position of the noise source.

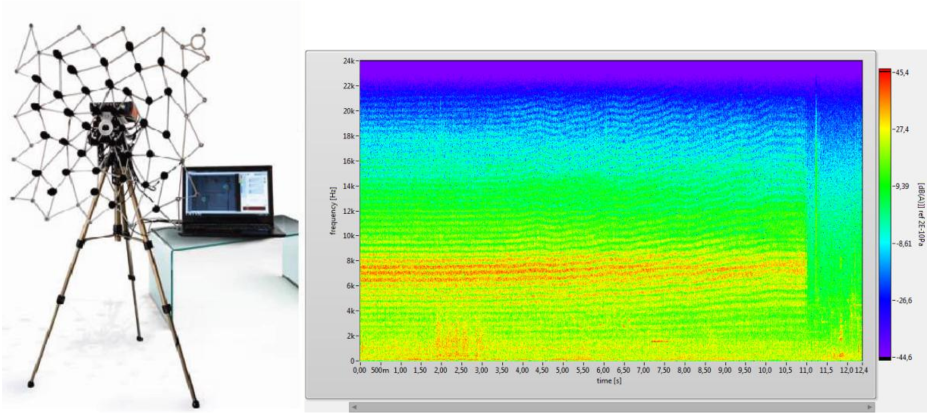
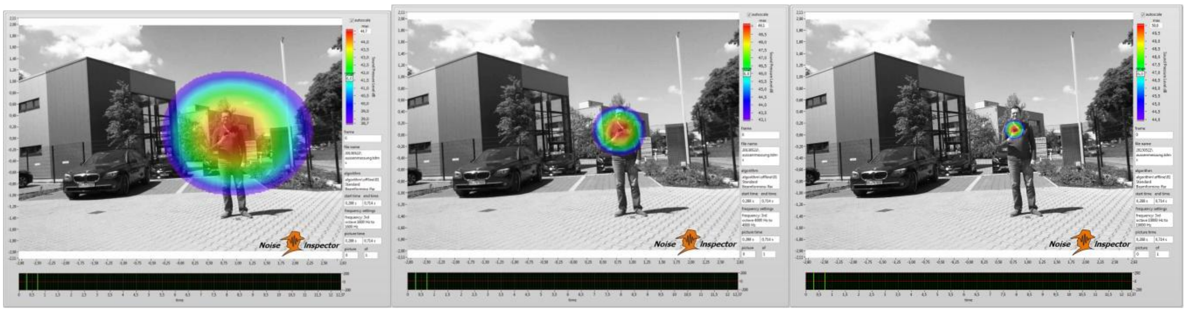


Fig. 5: The CAE „Spider-Array” and time-frequency analysis Graph [7]



(a) *(b)* *(c)*

Fig. 6: The results of Beamforming algorithm at 1,4 Ghz *(a)*, 6 GHz *(b)* and 10 GHz *(c)*

(a) *(b)* *(c)*

Fig. 7: The results of Music algorithm at 1,4 Ghz *(a)*, 6 GHz *(b)* and 10 GHz *(c)*

Precision indicators are:

- The mean square error

$$\sigma_R = \sqrt{\sigma_x^2 + \sigma_y^2} \qquad (7)$$

σ_x şi σ_y - the standard deviation of the points position in the coordinate system of the own sensor's antenna

- Circular Error Probability

$$\sigma_c = 0{,}62\sigma_y + 0{,}56\sigma_x \qquad (8)$$

- Circular Error Probability for 95% confidence level

$$\sigma_c = 2{,}08 \cdot (0{,}62\sigma_y + 0{,}56\sigma_x) \qquad (9)$$

Table 1: The results for the three frequencies used

Algorithm	Frequency	σ_x [mm]	σ_y [mm]	σ_R [mm]	σ_c [mm]	σ_c 95% [mm]
Beamforming	1,6 GHz	733	506	891	724	1506
MUSIC		410	531	671	559	1162
Capon		546	495	737	613	1274
Clean SC		24	33	41	34	71
Beamforming	4 GHz	130	158	205	171	355
MUSIC		108	106	151	126	262
Capon		162	160	228	190	395
Clean SC		40	40	57	47	98
Beamforming	10 GHz	44	58	73	61	126
MUSIC		13	23	26	22	45
Capon		53	64	83	69	144
Clean SC		16	26	31	25	52

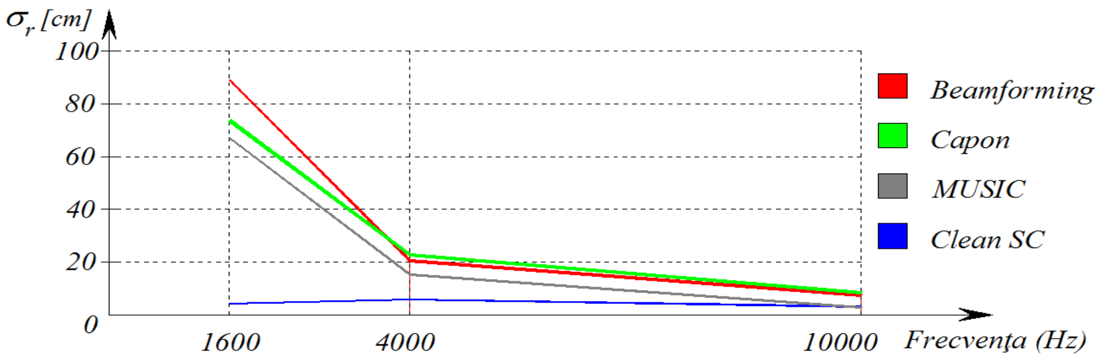


Fig. 8: Variation of mean squared error by frequency

Considering *S* correct position of the sound source and *S'* estimated position of the source, the difference between the two positions is given by the vector composed of position error estimation ε_X in the vertical plane and position estimation error ε_Y in horizontal plane between the correct position of the sound source and the estimated position. The two errors describe the estimation error of the direction of incidence of the received signal consists of the estimation error of the direction in horizontal plane εHz and vertical plane ε_V. At the end of this chapter were prepared tables showing the comparative results for the three frequently used, by processing of each of the four algorithms.

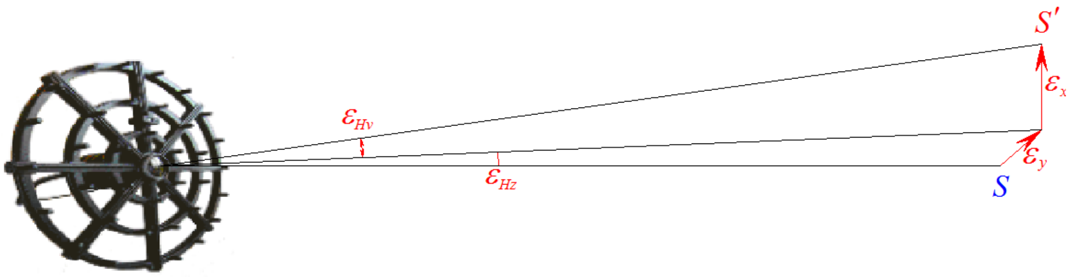


Fig. 9: Position estimation errors

Estimation errors in the direction of arrival of the received signal were determined on the basis of errors in horizontal and vertical position between the correct position of the sound source and the position estimated by the software based on the four algorithms at frequencies of 1.6, 4 and and 10 GHz. After comparing the results found a significant improvement in the accuracy of determining the direction of incidence of the received signal by changing the frequency by 1,6 at 4 GHz.

Table 2: The errors in the incident direction of the signal at 1.6, 4 şi 10 GHz frequencies

Algorithm	Frequency [GHz]	ε_{Hz} [gon]	ε_V [gon]
Beamforming	1,6	3,7601	0,5477
MUSIC		2,1637	1,0185
Capon		5,4615	0,3820
Clean SC		2,5646	0,7639
Beamforming	4	0,3820	0,6366
MUSIC		0,5093	0,2546
Capon		0,5093	0,5393
Clean SC		0,5093	0,6366
Beamforming	10	0,2546	0,3820
MUSIC		0,2546	0,2546
Capon		0,5093	0,6366
Clean SC		0,3820	0,3820

The system has multiple applications in the practice of which can be mentioned: determining cracks in building, acoustic aerodynamic car analysis in a wind tunnel, analysis of the noise emission of certain equipment in operating condition. Starting from the definition of precision and accuracy, and assessing the results obtained in the four cases of the relationship between these two terms can be drawn a number of conclusions on the reliability of the used algorithms. From the results of processing can show that higher frequencies are significantly improved and Clean SC algorithm although the good values even for low frequencies with high precision, the accuracy of measurements is low, because in this case, the system identify the source of the noise in two different locations at a distance of 17 cm and 26 cm from the real source.

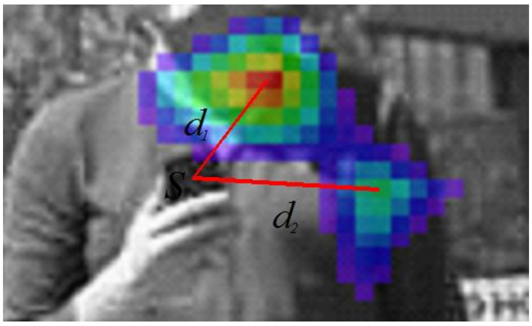


Fig. 10: The position erorr with Clean SC algorithm at 1,6 GHz frequency

When using low frequencies of 1.6 GHz for the other algorithms, both precision and accuracy offered are low. For beamforming algorithm, the maximum intensity recorded sound pressure which reached a maximum of 44.7 dB was recorded in an area equivalent to an ellipse whose semi-axis values were 59 cm and 40 cm, and whose center assigned sound source position was shifted by 29 cm from the actual position of the sound source.

Fig. 11: The position erorr with Beamforming algorithm at 1,6 GHz frequency

From the results of post-processing, it can be seen that the frequency of 10 GHz, leads to very good results both in terms of precision and the accuracy. Thus both the algorithm: Music, Beamforming, Capon and CleanSC image registration leading to an area occupied by the maximum intensity of the sound pressure position at a circle up to 6 cm for the worst case, but whose center is rigorously position of the sound source.

Conclusion

Positioning systems presented constitutes a current theme, and scientific interest in opening a new branch of research in terms of positioning for different areas of interest for this period. However these systems constitutes an interesting topic of interdisciplinary research in context of integration with GIS technology, and presents an important step in making connections between different areas. Given the very low level of popularity in our country of this systems, the present paper provides some perspectives for implementing these systems for various types of applications.

This system allows a positioning accuracy low in terms of the surveyor specialist, but cover to many related fields where precision requirements is not very restrictive.

A research perspective of this systems can constitute by improvement of techniques to determine the position of the environments indoor and to examine possibilities of improving positioning systems in these environments by integrating several techniques to determine the position within a single system to provide superior accuracy.

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