IMPACT POINT DETERMINATION FOR THE AIR-DROPPED BOMBS BY MEANS OF ACUSTIC METHODS. PART 2: EXPERIMENTAL STUDY

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***Abstract* – This paper represents the second part of a study on the determination systems for the impact points of the air-dropped bombs by means of acoustic methods. It tackles the experimental part of the study concerning the monitoring system. Firstly, the experimental system is presented, including the system for the acoustic signals detection and for signals' acquisition and processing. The experimental tests were performed in laboratory for known positions of the test points. The system estimates both the position of the impact point and the horizontal components of the wind speed by means of using a Marquardt-Levenberg estimation algorithm.**

Keywords: *impact point, air - dropped bombs, acoustic method, cross-correlation, Marquardt-Levenberg algorithm.*

1. INTRODUCTION

Previous studies ([1]), concerning the determination systems for the impact points of the air-dropped bombs by means of acoustic methods led to a system architecture with a 6 acoustic sensors network placed in a hexagonal shape (Fig. 1 [1]). The signals received by the acoustic sensors are radio transmitted to the processing and display system. We calculated the reference delay time by finding the number of delay samples between the prints of the audio signals received by two sensors and based on the sampling rate set for the system. The method used was cross-correlation ([2], [3]).

This method estimates both the position of the impact point in a horizontal plane and the two components of the longitudinal wind speed within the testing area. To estimate the 4 unknown values we used an Marquardt-Levenberg iterative method ([3], [4]). It minimises a sum of squares given by the determination of the time differences between the moments when the sensors 2÷6 and the sensor 1 received the audio signal.

For the numerical studies, 6 test points (TP) were simulated, three with a zero wind and three with a non – null; the maximum absolute errors were obtained for the test point in the center of the hexagon. For all the other test points, situated inside or on the tops of the hexagon, the estimation errors were under the limit of 10^{-3}, both for the position and for the wind speed.

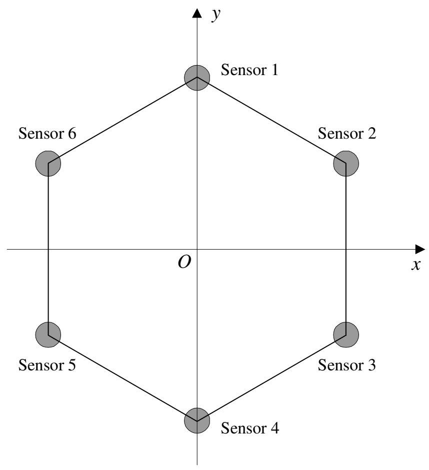

Figure 1: Hexagonal configuration of the sensors system

2. HOW TO PUT UP THE SENSORS SYSTEM AND THE SYSTEM FOR SIGNAL AQUISITION AND PROCESSING

To carry out the simulations the times we used were analytically calculated so the next step to develop the system's architecture was to use real signals. Acoustic data are often processed as the RMS (root mean square) of the pressure variation of the sound depending on the time. We use the formula

$$p_{rms} = \sqrt{\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} p^2(t) dt} \ , \qquad (1)$$

measured in Pascals. The time interval for which this value is calculated depends on the sampling rate of the acquired pressure signal. The quantity

$$L_p = 20 \log_{10}(p / p_0) \qquad (2)$$

is the signals' logarithmic form; the unit for measurement is the decibel. This is, in fact, the

sounds' pressure level. p_0 is 20 micro Pascal. The pressure level L_p varies too quickly to be possibly intercepted and, for most cases, generates a large amount of data.
To make it possible to use these data we may utilise a signal which, for a certain time interval, especially chosen, can be considered stationary; its level has the same RMS. This pressure level is defined as

$$L_{eq} = 20\log_{10}(p_{rms} / p_0). \tag{3}$$

Because we did not know precisely the frequencies spectrum for the signal received after the bomb's explosion, we decided to purchase acoustic sensors with the largest frequency band possible.
After comparing the available market prices, the sensors which were accessible and corresponded from the technical point were delivered by the Behringer company (Fig. 2). The technical characteristics of the sensors we used are the following: omni-directional, impedance 600 Ohm, sensibility -60 dB, frequency band Hz to 20 kHz.

Figure 2: Acoustic sensor

The amplitude – frequency characteristic on a logarithmic scale is presented in Fig. 3, while their directivity characteristic, in Fig. 4.

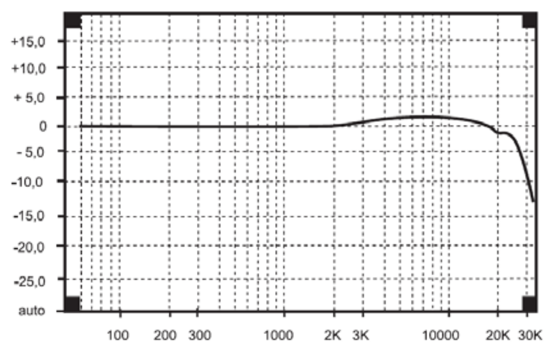

Figure 3: Amplitude-frequency characteristic of sensor

The sensors are used with a preamplifier, type MIC100 Tube UltraGain which uses 220Vac tension. Because each sensor from the system must be independent from the point of view of the functioning conditions (input tension) we chose the source to be put up using accumulators of 12Vcc, 12Ah, which give tension to a 12 Vcc invertor at 220Vac with a power of 600W; this source is used by the preamplifier.
The preamplifier serves to provide the corresponding input tension to the sensor with which it is set up, but also to get the sensor's signal in order to amplify and transmit it to the acquisition and processing system. The output signals given to the preamplifier by the sensor are conditioned by the former; they can be used, depending on their adjustment, both by the data telemetry system and, directly, by the acquisition and processing system.

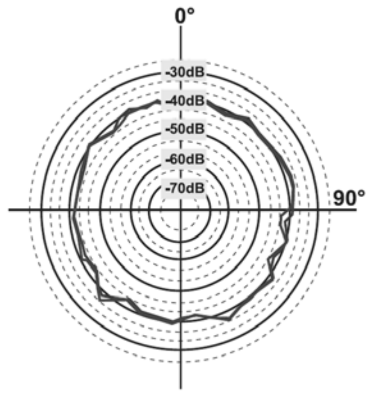

Figure 4: Directivity characteristic of sensors

The acquisition system was designed so that the system testing could be performed both in lab and field configurations. In a lab configuration the distances between the sensors are small and the signals from the sensors' system are taken by means of cables. On field, the signals are taken by means of a data telemetry system.
The architecture of the acquisition system was developed around a PC platform, industrial format (CPU 3.2 GHz, 1GB RAM). The operating system we used is Windows XP Professional. For signal acquisition we used a National Instruments DaqPad 6015 card, with a USB interface.
The acquisition Software was set up in Visual C# programming language. 6 analogic inputs are acquired with a sampling rate of 10000 samples/channel, differential input mode, ±5V.
The data acquired from the sensors are saved in files with a sar extension. To facilitate the analysis of the acquisition data we used *Matlab* environment, because it has a strong analysis and simulation motor.
At first, to process and analyse the signals supposes to put up their correlation in order to determine time differences among the signal received by sensor no. 1 and the rest of the system's sensors. The correlation process implies the use of the cross-correlation function which gives the difference from the samples between the signals, afterwards transformed in time differences based on the value of the sampling rate for which each channel of the acquisition card was set.
The time differences resulting from the previous stage are used in the process of estimating the four variables (position on *x* and *y*, wind speed on *x* and *y*) based on Marquardt-Levenberg algorithm used in theoretic numerical simulations ([1]).

3. THE SYSTEM'S EXPERIMENTAL TESTING WITHIN LAB CONDITIONS

For this particular situation, the radio connection was replaced by cables connecting the sensors to the acquisition system.

The sensors were placed on the tops of a hexagon with a radius of 10m.The acquisition system was manually started before producing the noises to simulate an explosion. The noises were produced in different locations, with determined positions, within the space delimited by the sensors.

A number of 8 tests were performed; testing points are located as in Fig. 5. Their coordinates are measured in m.

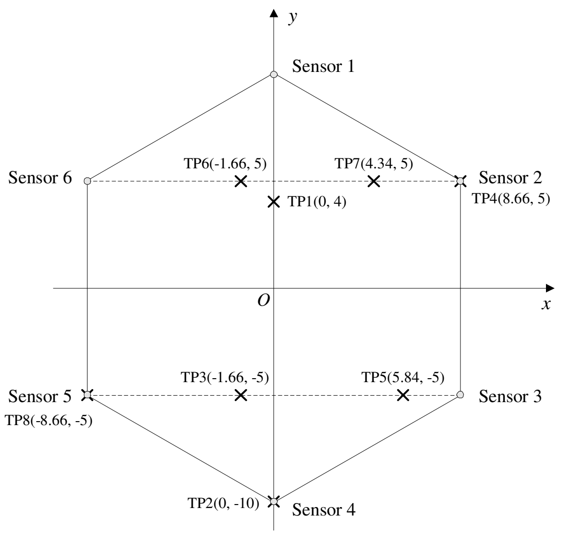

Figure 5: Test points positions for experimental study

For the 8 test points, the difference in sample number (Δs) and in time (Δt expressed in s) between the signal received sensor no. 1 and the other sensors are presented in Table 1, while the estimates for position (x^e, y^e expressed in m), wind speed(v^e_{alx}, v^e_{aly} expressed in m/s) and positioning error (Δx, Δy expressed in m) are presented in Table 2.

TP	Delay	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
TP1	Δs	-610	-1730	-1810	-1430	-530
	Δt	-0.0061	-0.0173	-0.0181	-0.0143	-0.0053
TP2	Δs	790	2880	5510	2860	790
	Δt	0.0079	0.0288	0.0551	0.0286	0.0079
TP3	Δs	330	1640	3230	2520	880
	Δt	0.0033	0.0164	0.0323	0.0252	0.0088
TP4	Δs	2740	10	-2070	-2870	-210
	Δt	0.0274	0.0001	-0.0207	-0.0287	-0.021
TP5	Δs	1780	4270	2740	560	-430
	Δt	0.0178	0.0427	0.0274	0.0056	-0.0043
TP6	Δs	-1340	-2440	-2530	-1660	-250
	Δt	-0.0134	-0.0244	-0.0253	-0.0166	-0.0025
TP7	Δs	720	-1380	-2780	-3030	-1960
	Δt	0.0072	-0.0138	-0.0278	-0.0303	-0.0196
TP8	Δs	-780	0	2140	4680	2170
	Δt	-0.0078	0	0.0214	0.0468	0.0217

Table 1: Δs and Δt for all test points

TP	x^e	y^e	Δx	Δy	v^e_{alx}	v^e_{aly}
TP1	-0.114	3.459	0.114	0.540	-9.999	-9.999
TP2	0.084	-8.844	-0.084	-1.155	-1.665	-7.641
TP3	-1.571	-5.192	-0.088	0.192	3.203	-9.999
TP4	7.892	4.625	0.767	0.374	4.333	-1.123
TP5	6.402	-5.655	-0.562	-0.655	-2.077	-0.537
TP6	-1.675	4.167	0.015	0.832	-6.465	6.156
TP7	4.497	5.339	-0.157	-0.339	-0.317	-1.558
TP8	-8.806	-4.920	0.146	-0.079	4.303	-0.916

Table 2: Estimates and errors for all test points

The signals acquired from the sensors during the 8 tests are shown as follows: Fig. 6 – TP1(0, 4); Fig. 7 – TP2(0, -10); Fig. 8 – TP3(-1.66, -5); Fig. 9 – TP4(8.66, 5); Fig. 10 – TP5(5.84, -5); Fig. 11 – TP6(-1.66, 5); Fig. 12 – TP7(4.34, 5); Fig. 13 – TP8(-8.66, -5).

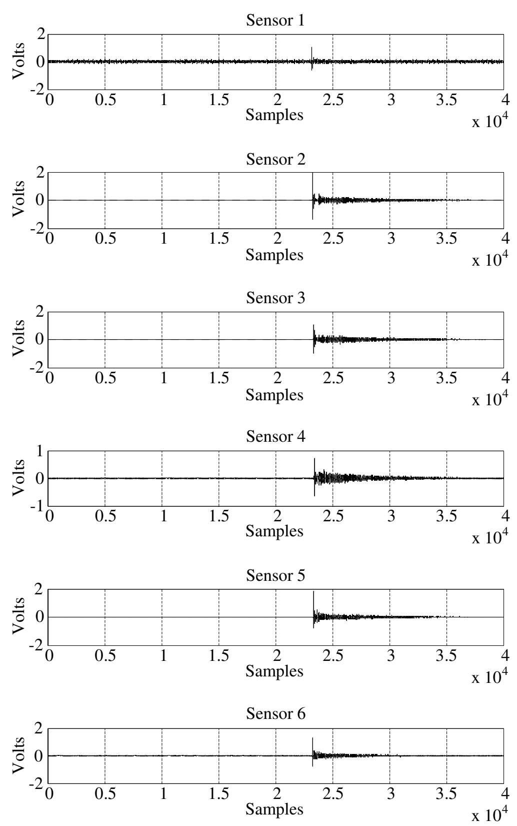

Figure 6: Signals acquired from the sensors for TP1

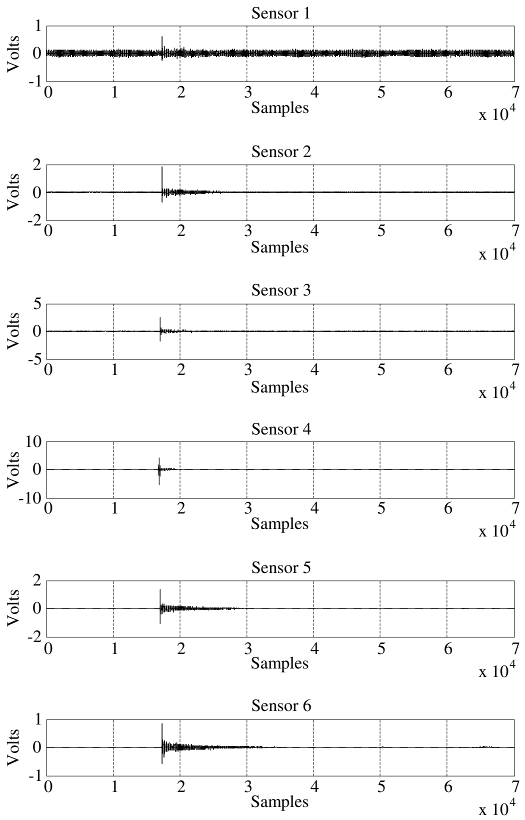

Figure 7: Signals acquired from the sensors for TP2

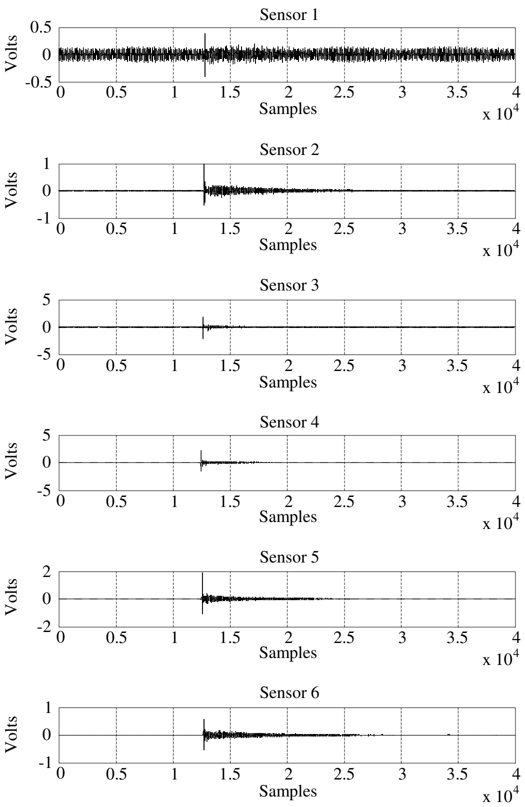

Figure 8: Signals acquired from the sensors for TP3

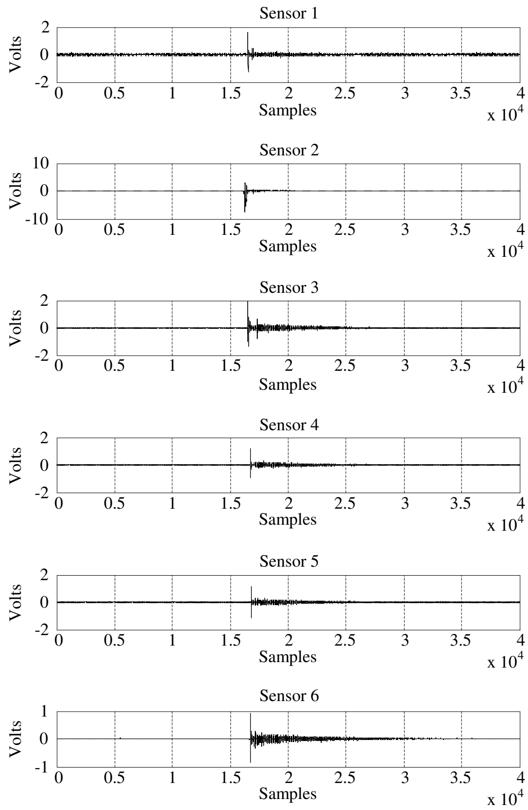

Figure 9: Signals acquired from the sensors for TP4

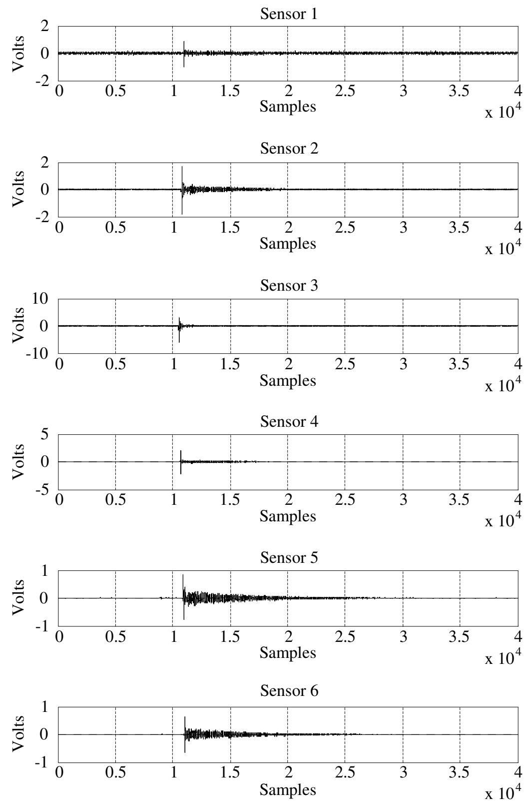

Figure 10: Signals acquired from the sensors for TP5

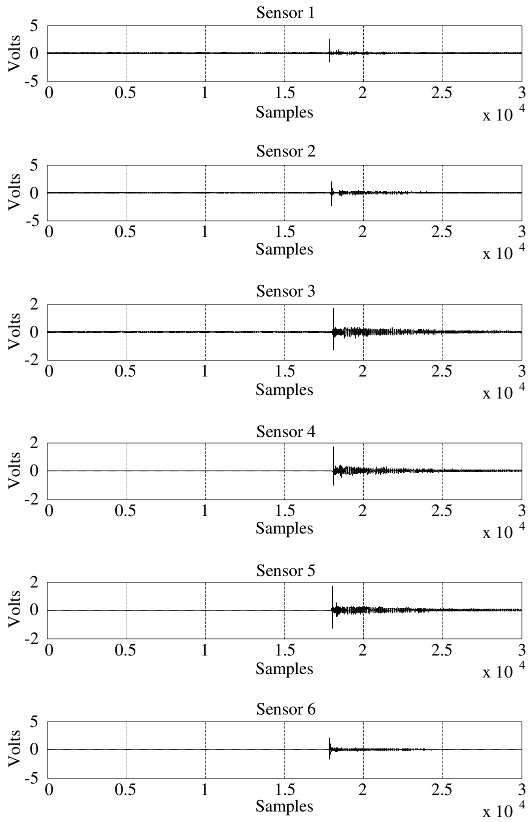

Figure 11: Signals acquired from the sensors for TP6

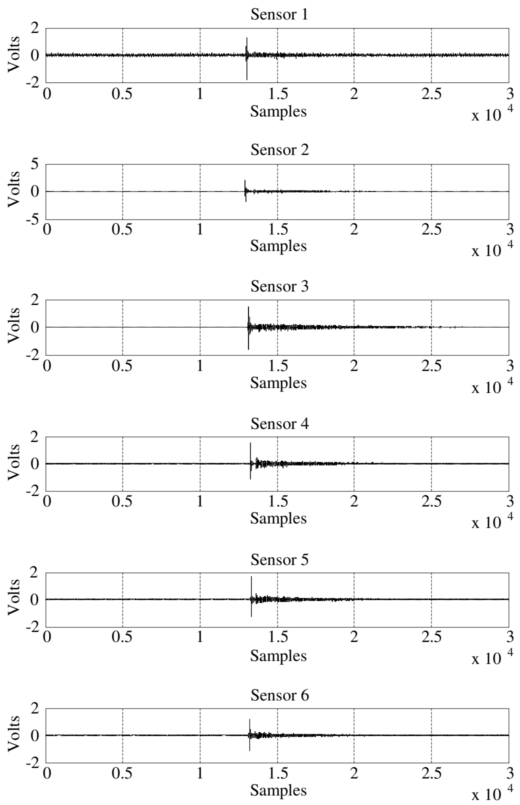

Figure 12: Signals acquired from the sensors for TP7

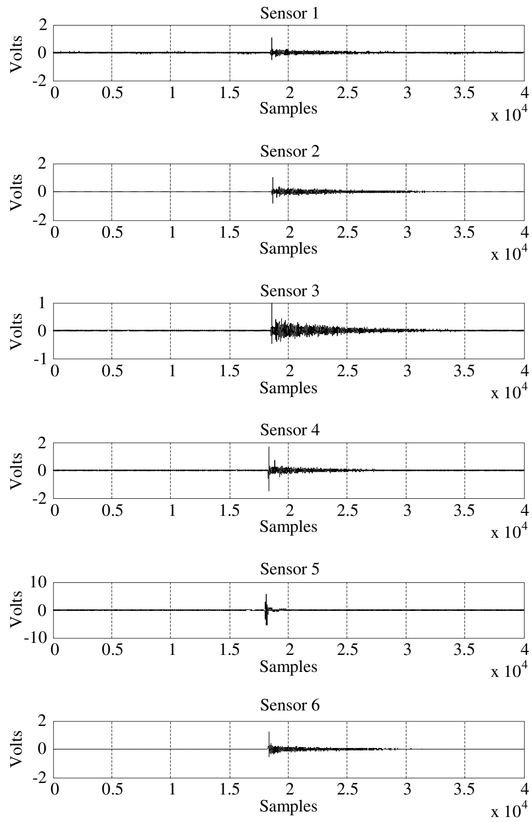

Figure 13: Signals acquired from the sensors for TP8

We notice that the average value of the absolute error of positioning is 0.2416 m on the x axis and 0.5208 m on the y axis. For some cases there are also leaps of up to one meter in error. The absolute top values to estimate position were registered for TP4 (on x channel 0.767 m) and for TP2 (on y channel 1.155 m). To notice that top errors are registered on the y channel; they exceed 0.2 m for 6 test points, as compared to the x channel where the value of 0.2 m is exceeded only for two test points.

The main cause for the average error is very small distance between sensors, which leads to obtaining small time differences determined with a low resolution.

The error leaps are due, on one hand, to the signals' tampering because of the lab equipments placed on the testing location, and on the other hand, to the position where the signal source was generated: on noise generating, in some cases, between the sensors and the signal source there was a juxtaposition with portions from the body of the person who performed the operation (the estimate of the wind speed is also seriously influenced). Another error source, especially to estimate wind speed, is offered by the enclosure where the tests were performed; it had very good acoustics but also portions where air currents were very strong.

The results we obtained are very good, considering that the real distance separating the sensors from the center of the hexagon is 50 times larger than in the case we tested (500 m instead of 10 m). So, the times to spread will be 50 times larger. This experimental test validates the functioning of the algorithm to estimate position and wind speed Marquardt-Levenberg method, and also validates the method to determine the delay time in receiving an acoustic signal between two sensors which use cross-correlation.

4. CONCLUSIONS

The paper validated through experimental lab testing an acoustic method to determine impact points of the air-dropped bombs.

This method estimates both the position of the impact point in a horizontal plane and the two components of the longitudinal wind speed within the testing area. To estimate the 4 unknown values we used an Marquardt-Levenberg iterative method which minimises a sum of squares given by the determination of the time differences on receiving an audio signal by more acoustic sensors.

We calculated the reference delay time by comparing the prints of the audio signals received by two sensors, based on the function called cross-correlation. The system consisted of 6 acoustic sensors placed on the tops of a hexagon with a 10 m side, we calculated the time differences between sensors 2÷6 and sensor no.1.

The test was performed for 8 test points, placed both inside and on tops of the hexagon (juxtaposed with the sensors). The average values of the absolute errors of positioning were 0.2416 m on the *x* axis and 0.5208 m on the *y* axis. The top absolute values to estimate position were registered for TP4 (on channel *x* 0.767 m) and for TP2 (on channel *y* 1.155 m). To notice that the largest errors were registered for channel y; they exceed 0.2 m for 6 test points, as compared to x channel where 0.2 m was exceeded for only two test points.

As main cause of the average error we identified the small distance among sensors which led to obtaining small time difference, determined with a low resolution. Thus, the results we obtained are very good, considering that the real distance separating the sensors from the center of the hexagon is 50 times larger than in the case we tested (500 m instead of 10 m). So, the times to spread will be 50 times larger.

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