EXPERIMENTAL INVESTIATION OF HYDROACOUSTIC MULTI-SENSOR ARRAY IN WATER TANK

KAROL LISTEWNIK

Polish Naval Academy
69, Śmidowicza St., 81-103 Gdynia, Poland
K.Listewnik@amw.gdynia.pl

The paper presents the experimental research associated with hydroacoustic multi-sensor array which is used for positioning object in water environment. Moreover, the paper presents the methodology of determination of target localization from bearing angles, and its accuracy. The construction of multi-sensor array consist of four hydrophones and it has a shape of a tetrahedron. This three-dimensional array is well known as a good solution of passive sonar and it is made of four elements assumed to have identical features and lying on a plane. The position of each hydrophones in a tri dimensional coordinate system correspond to the direction of the arriving acoustic plane wave. These features cause that the tetrahedral antenna has significant civil and military applications.

INTRODUCTION

The ship is a complex source of underwater noises and its hull vibrations are generating acoustic waves. In military technique, this fact is used to detection, classification, identification of type of moving ship and estimation ships movement parameters. Furth more, knowledge about position of sea objects (as sources underwater soughs) is relevant part of military technique, especially silent passive defense systems.

The researches of the Polish Naval Academy more than thirty years has been leading investigations related with experimental research the transmission of the acoustic energy generated by moving objects into the sea water and localization of sound's sources. The main aim of investigations were:

1. The determine of bearing angles each pairs of hydrophones with using effective method to determine phase shift (LabVIEW, MATLAB).
2. To test correctness of algorithms of description target's parameters by acoustic multi--sensor array.
3. To prepare acoustic multi-sensor array to measure in real conditions at sea environment.

1. METHOD OF INVESTIGATION

The multi-sensor array consist of tetrahedron arrangement of four hydrophones with various aperture is shown in Fig. 1. The investigation of multi-sensor array has been investigating in measurement water tank in Hydroacoustics Institute. During this investigations were used four hydrophones and underwater sound source (loud speaker). The arrangement of investigated array in measurement tank is presented in Fig. 2.

The laboratory with water tank was equipped with:

- Signal generator AGILENT 33220A,
- Amplifier IPA 300T,
- Sound source LUBELL Labs LL9162,
- Hydrophones RESON TC4032,
- Oscilloscope Tektronix TDS3054B,
- A/D transducer NI cDAQ-9223,
- Four-channel moduł NI cDAQ-9188 – fs = 50 kHz/channel,
- Control computer,
- Matlab and LabVIEW applications to simulate and calculate bearing angles.

The first step was calculated phase shift between received signals from two adjacent hydrophones:

$$\varphi = \frac{2 \cdot \pi \cdot x}{\lambda} = 2 \cdot \pi \cdot \frac{d \cdot \sin\alpha}{\lambda} \tag{1}$$

where:
x – difference of ways acoustic plane wave received form hydrophones 1 i 2,
d – distance beetwen hydrophones 1 i 2,
λ – length of ways acoustic plane wave.

Rule no 1 allows calculate angle α, and the direction of the first arriving sound:

$$\alpha = \arcsin(\frac{\varphi\lambda}{2\pi d}) \tag{2}$$

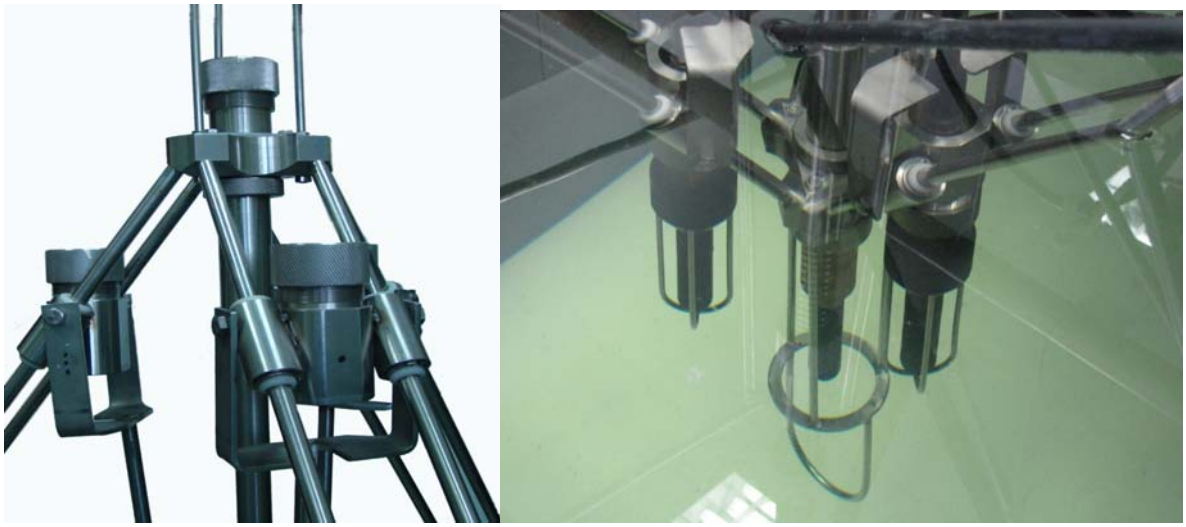

Fig. 1. The fragment of construction of multi-sensor array. On the left without hydrophones, on the right with hydrophones in water tank

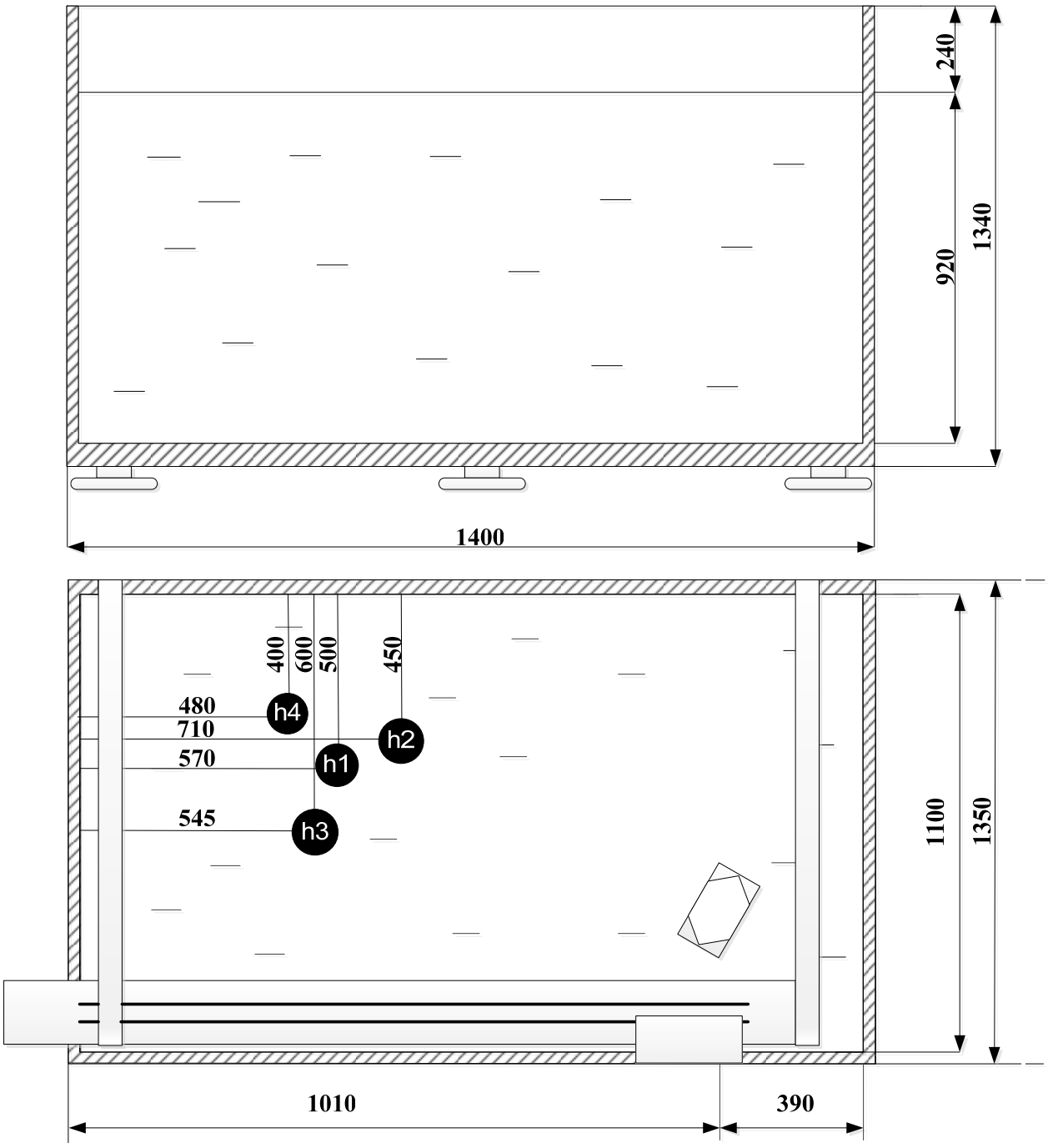

Fig. 2. The arrangement of investigated array in measurement tank

Flow chart of simulation programme (LabWIEV) is presented in Fig. 3.

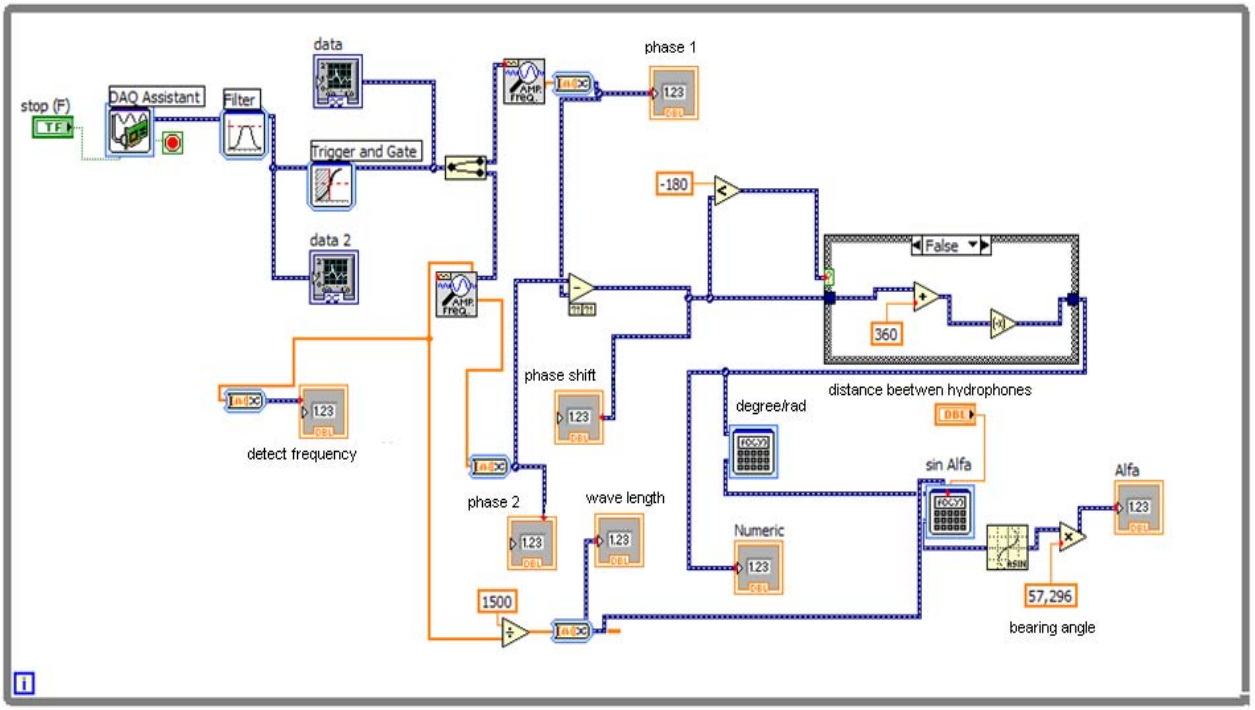

Fig. 3. Flow chart of LabVIEW simulation applications to description bearing angle from two hydrophones

Dimensions of water tank limits frequency of generated signal. Generated frequency was set up equal 15 kHz (signal without distortion). The signals was filtered by LabVIEW function *Trigger and Gate*. This functions allows to extract low and high frequency noise from measured signals. The best results of phase estimation gave LabVIEW block *Extract Single Tone Information*.

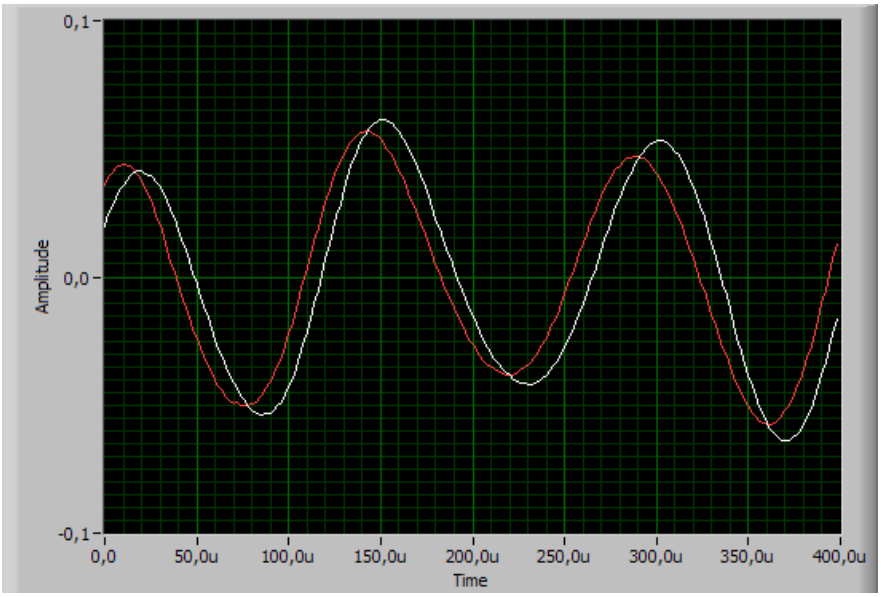

Fig. 4. Time waveform of phase shift two signals (after filtering)

During these laboratory measurements were used four hydrophones RESON TC4032 from the same series. In next step, it was carried out verification of accuracy measurement channel by insert voltage calibration's method. Time waveform of phases shift four signals after filtering is shown in Fig. 5.

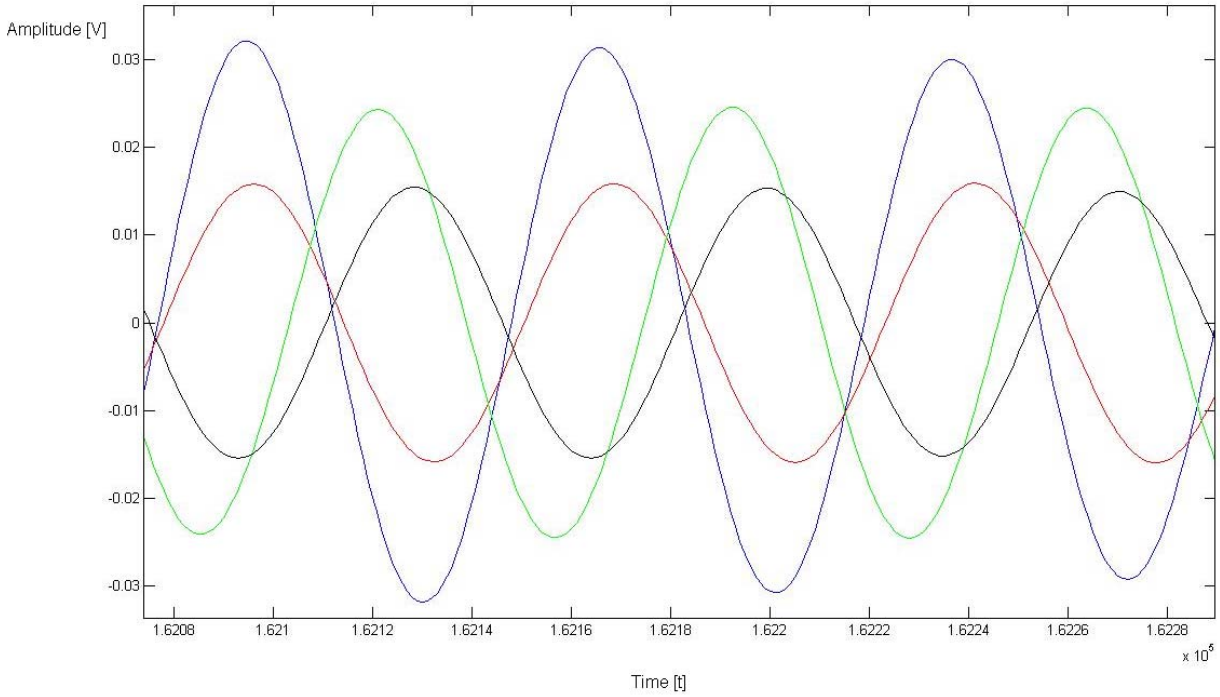

Fig. 5. Time waveform of phases shift four signals (after filtering)

2. RESULTS OF RESEARCH

Before this examinations, it was necessary to build simulate application to calculate elevation and azimuth angles based on six measurement pairs (from four hydrophones). Code was written in MATLAB language The MathWorks Company. The code was included to application wrote earlier in LabVIEW.

Flow chart of simulation application used to description elevation and azimuth angles of target (sound source) in arrangement of four hydrophones is presented in Fig. 6.

Function *MATLAB script* allows import files which was created in MATLAB to LabVIEW. INPUT and OUTPUT control blocks enable data manipulation for all data of code In MATLAB. To run application is necessary to have MATLAB 6.5 version or earlier and import to LabVIEW server scripts and libr ary of *dll*.

The examples of result are presented on Fig. 7 (Front panel with elevation, azimuth and bearing angles of pairs of hydrophones), Fig. 8 (Method of generating accurate estimates of azimuth and elevation angles of a target) and accuracy of measurement channels and simulation application is shown in Fig. 9.

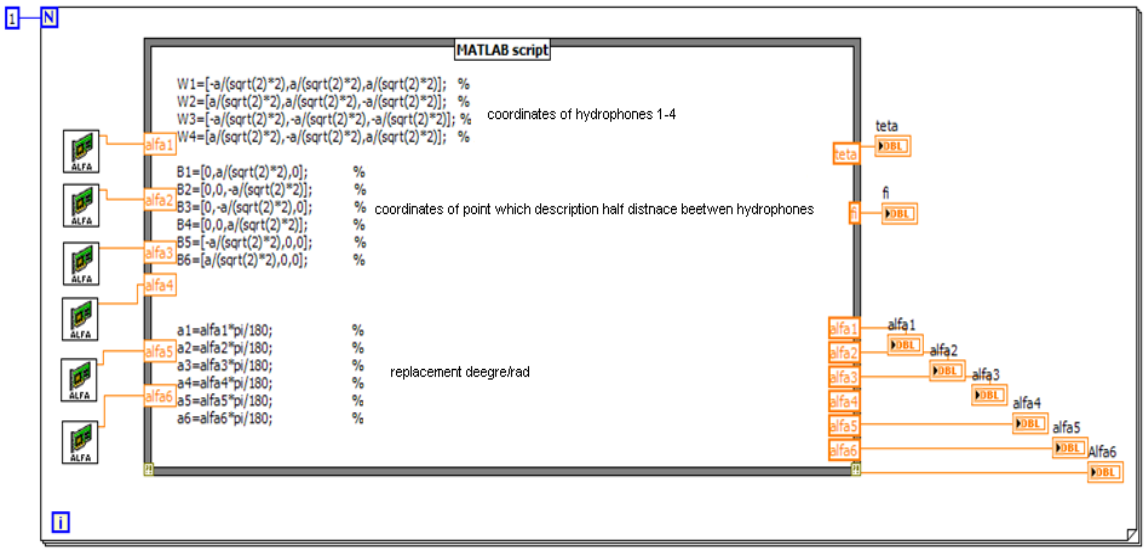

Fig. 6. Flow chart of simulation application used to description elevation and azimuth angles of target (sound source) in arrangement of four hydrophones

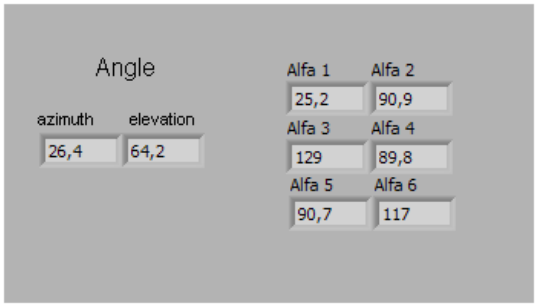

Fig. 7. Front panel of simulation application in LabVIEW

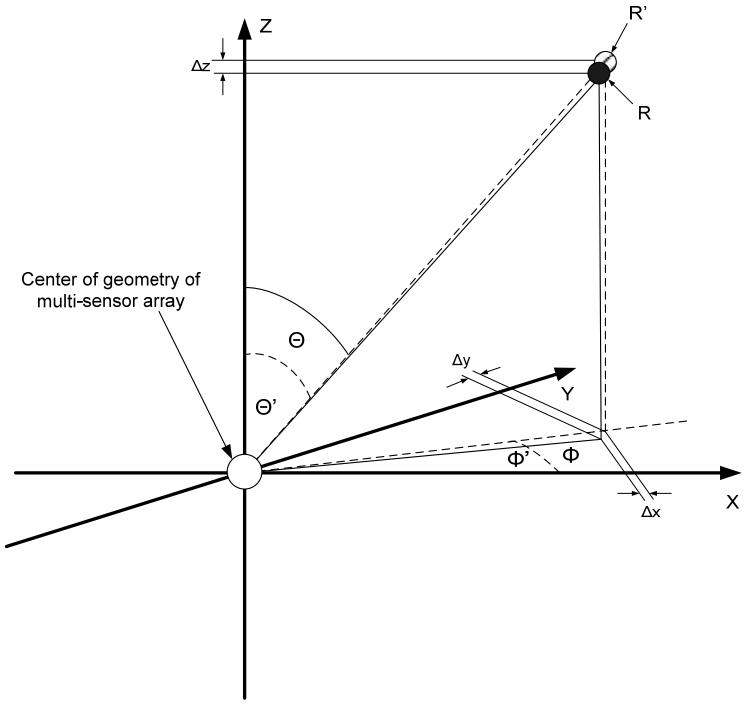

Fig. 8. Method of generating accurate estimates of azimuth and elevation angles of a target

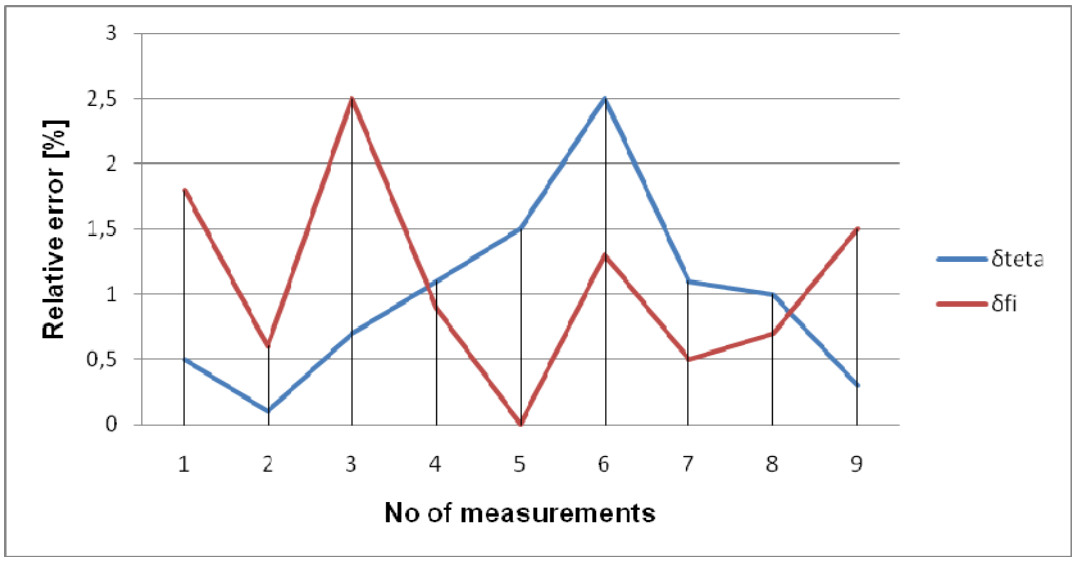

Fig. 9. Relative error of elevation and azimuth angles of target

3. SUMMARY

Multi-sensor array in shape of tetrahedral is relatively new solutions. This three-dimensional array is well known as a good solution of passive sonar and it is made of four elements assumed to have identical features and lying on a plane. The position of each hydrophones in a tri dimensional coordinate system correspond to the direction of the arriving acoustic plane wave. These features cause that the tetrahedral antenna has significant civil (e.g. USBL (Ultra-short baseline) as a method of underwater acoustic positioning in UUV) and military applications (silent passive sonar to detection and localization coordinates of target).

Based on the experimental investiation of hydroacoustic multi-sensor array it is possible to get conclusion about suitability to localization sound sources in real water envinroments.

The experience gathered during research localization with using multi-sensor array showed good accuracy of preparing equipment and MATLAB and LabIEW applications.

These investigation should be re-enact in real conditions in Baltic sea environment.

ACKNOWLEDGMENTS

The investigation was supported by the Ministry of Science and Higher Education (Grant No OR00 0047 08).

REFERENCES

[1] Czajkowski G., Ilczuk J., Koperski K., Wądołowski A., Programmable analyser of signals GC-89, Instruction Manual, Warsaw 1991.

[2] Fundamentals of underwater sound, OGP, 2008. http://www.iagc.org /.../OGP_IAGC_ Fundamentals_Underwater_Sound_No406_2008_05.pdf.

[3] Hansen C., Fundamental of acoustics. http://www.who.int /occupational_health/ publications/noise1.pdf.

[4] National Instruments: LabVIEW Fundamentals, 2005.

[5] National Instruments: Getting Started with LabVIEW, 2005.
[6] RESON 'Hydrophone TC4032', http://www.reson.com.
[7] Salamon R., Hydrolocations Systems, Gdansk 2006.
[8] Sherman C. H., Butler J. L., Transducers and Arrays for Underwater Sound, 2008.
[9] Sonar Acoustics Handbook, La Spezia, Italy, 2008.
[10] Tucholski E. J., Underwater Acoustics and Sonar. SP411 Handouts and Notes. Fall 2006, http://usna.edu/Users/physics/ejtuchol/.
[11] Urick R. J., Principles of underwater sound 3rd edition, Los Altos, 1983.