Acoustic radar employing particle velocity sensors

Józef Kotus, Andrzej Czyzewski

Multimedia Systems Department, Gdansk University of Technology, Narutowicza 11/12, 80-233 Gdańsk, Poland
{joseph,andcz}@sound.eti.pg.gda.pl

Abstract. A concept, practical realization and applications of a passive acoustic radar to automatic localization, tracking of sound sources were presented in the paper. The device consist of the new kind of multichannel miniature sound intensity sensors and a group of digital signal processing algorithms. Contrary to active radars, it does not emit the scanning beam but after receiving surroundings sounds it provide information about the directions of incoming acoustical signals. Practical examinations of the sensitivity and accuracy of the developed radar were also presented and discussed. The sensitivity of the realized acoustic radar was examined in free sound field. Several kinds of sound signals were used, such as: pure tone from 125 to 16000 Hz, one third octave band noise in the same frequency range and impulsive sounds. The obtained results for every kind of signal groups were presented and discussed. As results from experiments, in some cases even the small value of the signal to noise ratio was sufficient to localize sound source correctly. A video camera can be pointed automatically to the place the detected acoustical source is localized. Hence, the information about the sound event direction can be used to automatic and remote control of the PTZ (Pan Tilt Zoom) cameras. The automatic and continuous tracking in real time of the selected sound source movement is also possible. The proposed solution can significantly improve the functionality of the traditional surveillance monitoring systems.

Keywords: acoustic radar, sound intensity, source localization

1 Introduction

A concept, practical realization and applications of a passive acoustic radar to automatic localization and tracking of sound sources were presented below. Contrary to active radars, it does not emit the scanning beam but after receiving surroundings sounds it provide information about the directions of incoming acoustical signals. The device consist of the new kind of multichannel acoustic vector sensor (AVS) invented by the Microflown company [1] and a group of digital signal processing algorithms developed in the Multimedia System Department, Gdansk University of Technology [2]. Concerning the acoustic properties, beam forming arrays have lower frequency limitations and a line (or plane) symmetry. Data from all measurement points have to be collected and processed first in order to obtain correct results. The acoustic vector sensor approach is broad banded, works in 3D, and has a better mathematical robustness [3]. The ability of a single AVS to rapidly determine the bearing of a wideband acoustic source is of essence for numerous passive monitoring systems.

2 Acoustic particle velocity sensors

The single acoustic vector sensor measures the acoustic particle velocity instead of the acoustic pressure which is measured by conventional microphones, see e.g. [4]. It measures the velocity of air across two tiny resistive strips of platinum that are heated to about 200°C, see Fig. 1. It operates in a flow range of 10 nm/s up to about 1 m/s. A first order approximation shows no cooling down of the sensors, however particle velocity causes the temperature distribution of both wires to alter. The total temperature distribution causes both wires to differ in temperature. Because it is a linear system, the total temperature distribution is simply the sum of the temperature distributions of the two single wires. Due to the convective heat transfer, the upstream sensor is heated less by the downstream sensor and vice versa. Due to this operation principle, the Microflown can distinguish between positive and negative velocity direction and it is much more sensitive than a single hot wire anemometer and because it measures the temperature difference, the sensitivity is (almost) not temperature sensitive [5].

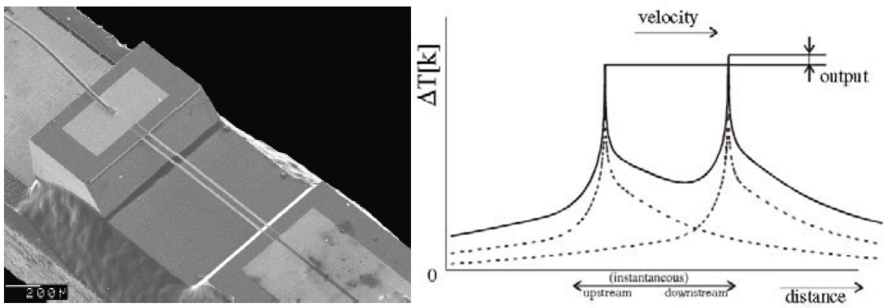

Fig. 1. (Left) A microscope picture of a standard Microflown. (Right) Dotted line: temperature distribution due to convection for two heaters. Both heaters have the same temperature. Solid line: sum of two single temperature functions: a temperature difference occurs [5]

Each particle velocity sensor is sensitive in only one direction, so three orthogonally placed particle velocity sensors have to be used. In combination with a pressure microphone, the sound field in a single point is fully characterized and also the acoustic intensity vector, which is the product of pressure and particle velocity, can be determined [6]. This intensity vector indicates the acoustic energy flow. With a compact probe as given in Fig. 2, the full three dimensional sound intensity vector can be determined within the full audible frequency range 20 Hz up to 20 kHz.

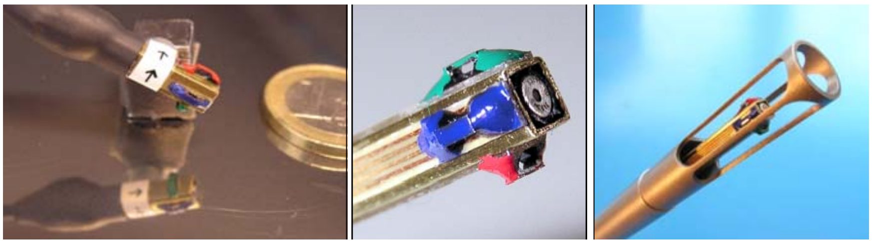

Fig. 2. A standard three dimensional sound probe (three orthogonally placed Microflowns and a 1/10" sound pressure microphone in the middle). For size comparison one Euro is shown [5]

3 The algorithm of the acoustic radar

The algorithm of the passive acoustic radar is based on 3D sound intensity component determination. Its diagram was presented in Fig. 3. In the first step, the particular acoustic signals are captured and prepared to frequency analysis. In the second step, the dominant frequency of the sound is estimated based on the FFT coefficients and using Quinn's First Estimator [7]. Next, the frequency value is used to design the narrow-band recursive filter [8]. The result of the recursive filtration is finally used to compute the particular sound intensity components.

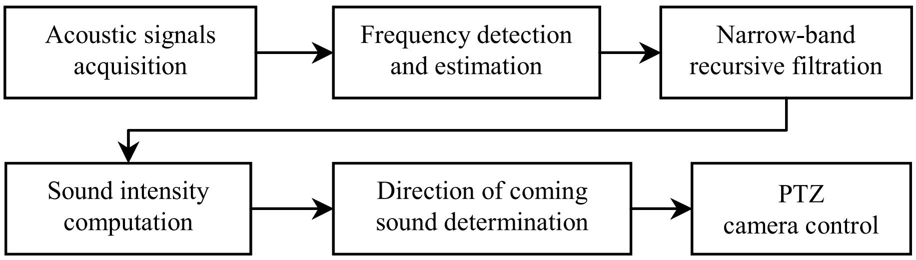

Fig. 3. The block diagram of the passive acoustic radar algorithm

Sound intensity is the average rate at which sound energy is transmitted through a unit area perpendicular to the specified direction at the point considered. The intensity in a certain direction is the product of sound pressure (scalar) $p(t)$ and the particle velocity (vector) component in that direction $u(t)$. The time averaged intensity I in a single direction is given by Eq. 1 [5]:

$$I = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} p(t)u(t)dt \quad \textbf{(1)}$$

It is important to emphasize that using the presented 3D AVS, the particular sound intensity components can by simply obtained just based on Eq. 1. The sound intensity vector in three dimensions is composed of the acoustic intensities in three orthogonal directions (x,y,z) and is given by Eq. 2 [9]:

$$\vec{I} = I_x \vec{e}_x + I_y \vec{e}_y + I_z \vec{e}_z \quad \textbf{(2)}$$

In presented algorithm the time average T was equal to 4096 samples (sampling frequency was equal to 48000 Hz). It means that the direction of the sound source was updated more than 10 times per second.

4 Practical evaluation of the acoustic radar

The practical examinations of the sensitivity and accuracy of the developed radar were conducted in anechoic chamber (free field). Several kinds of sound signals were used, such as: pure tone from 125 to 16000 Hz, one third octave band noise in the same frequency range and impulsive sounds. The set up of the measuring system was presented in Figs 4 and 5. The acoustic sound pressure level was additionally independently determined using Bruel&Kjær PULSE measurement system type 7540 with microphone type 4189, calibrated before the measurements using the acoustic calibrator type 4231. The intensity probe and measuring microphone were located in the same place to ensure identical acoustic field condition.

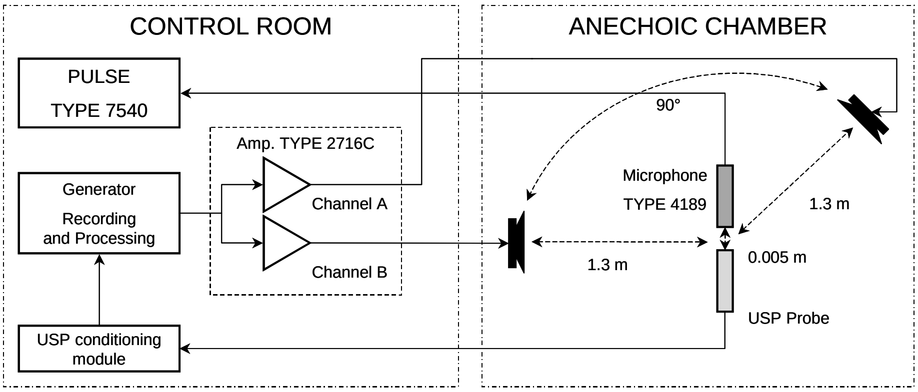

Fig. 4. Block diagram and equipments used during the measurements

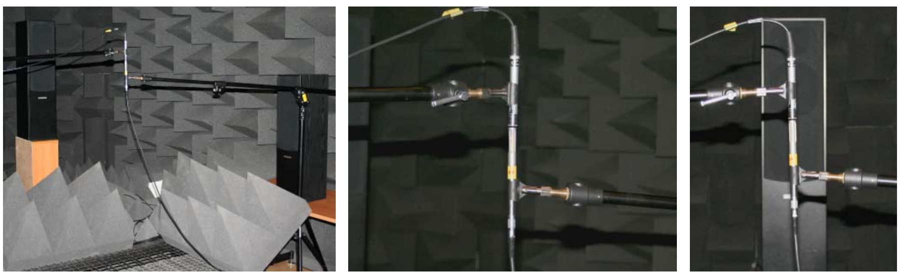

Fig. 5. Details of the measurements set up

The pure tone and noise test signal for particular frequency were presented twice. In first time only test signal from one loudspeaker was emitted. The test signal has two phases: starting phase with constant sound level of the sound and decay phase in which the sound level was monotonously decreased 1dB/s. Next, the same test signal was presented simultaneously with the additional disturbing pink noise. For both session the sound pressure level and angle value were noticed. Additionally, the sound level of the background noise for both sessions was determined. Such kind of data were used to properly compute the sensitivity of the radar expressed by the absolute sound pressure level and its accuracy in the disturbing conditions expressed by the Signal-To-Noise ratio as is in Eq. 3, for particular frequencies [10],[11].

$$SNR_{dB} = SPL_{Signal\ dB} - SPL_{Noise\ dB} \tag{3}$$

To properly obtain the SNR_{dB} indicator the two sessions of the measurements were required. During the first session, the $SPL_{Signal\ dB}$ was determined. In the next session, the background noise level was obtained ($SPL_{Noise\ dB}$). For that session the test signal was presented from one loudspeaker and the noise from another loudspeaker. For that conditions the values of the angle of the sound source were determined.

5 Measurement results

The measurements were performed for different configurations of the AVS signal conditioning module. The frequency correction for the particle velocity channels could be switch off or on. The example measurement results were presented for both configurations of the conditioning module, but combined results were presented for correction switch on only.

5.1 The pure tone measurement results

In Fig. 6 the example measurement results for 1kHz pure tone were presented.

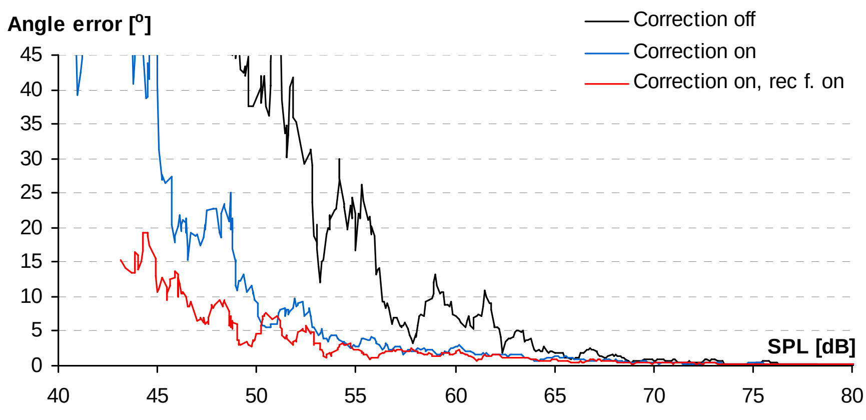

Fig. 6. Example measurement results for pure tone (1000 Hz), reference level: 20 µPa.

The disturbing noise sound source was off. The black line was obtained when the frequency correction was switched off. The greatest error values was obtained in such a case. When the frequency correction was switch on (blue line), the error level essentially decreased. The application of the recursive filtration algorithm for the given frequency additionally increased the accuracy of the sound source localization. The broadband background noise level for that measurements was equal to 45 dB SPL.

In Fig. 7 the example angle error as a function *SNR* level for 2000 Hz pure tone was presented.

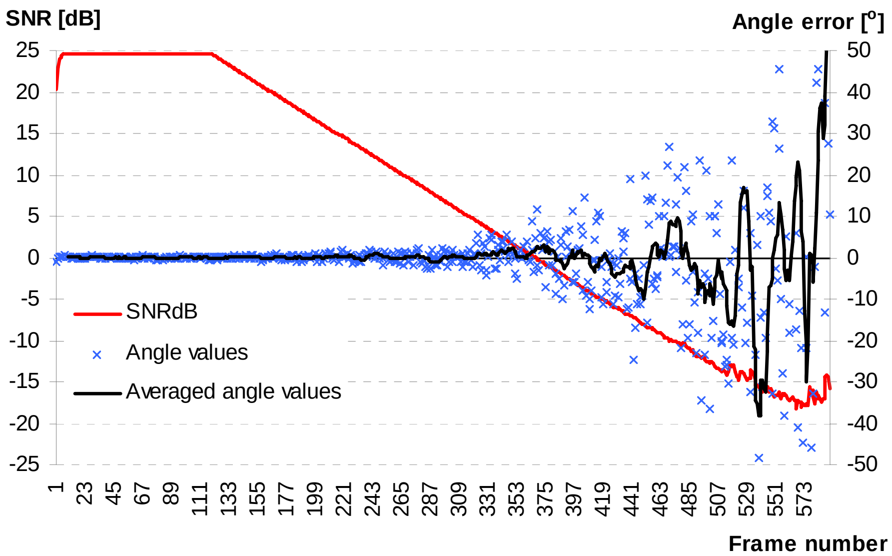

Fig. 7. Example angle error as a function of the *SNR* level for 2000 Hz

In that case, the disturbing noise source was on and its level was equal to 62 dB SPL. The recursive filtration was applied. The red line presents the SNR_{dB} values. The black line was used for averaged angle values. Small blue crosses indicates the particular values of the angle error. It is important to emphasize that the very high accuracy is obtained, even for negative values of the *SNR*. Rough estimate of the coming sound direction was obtained for extremely low *SNR* values.

The combined SNR_{dB} results for all examined frequencies were presented in Figs 8 and 9 (the recursive filtration applied). The values were assigned for given accuracy levels: ±1°, ±3°, ±5°, ±10°, ±15°, ±30°and ±45°. Taking obtained results into consideration, it was asserted that the developed algorithm of the passive acoustic radar have very good features in continuous pure tone tracking for all considered frequencies.

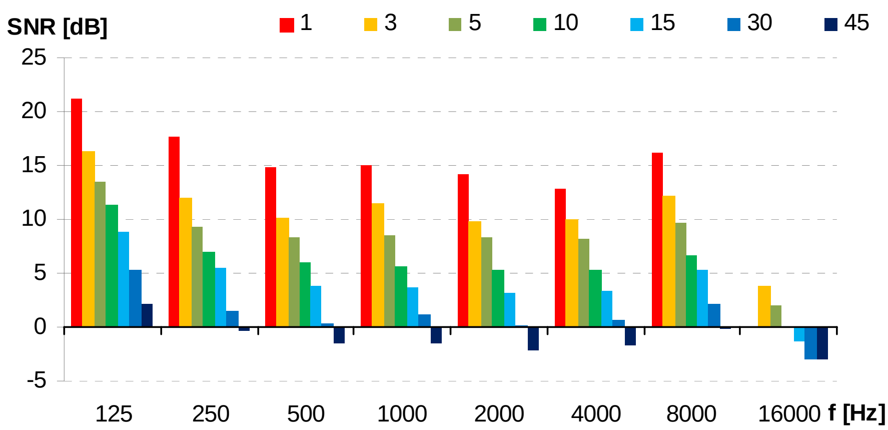

Fig. 8. Combined SNR_{dB} results for all examined frequencies. The recursive filtration was not applied

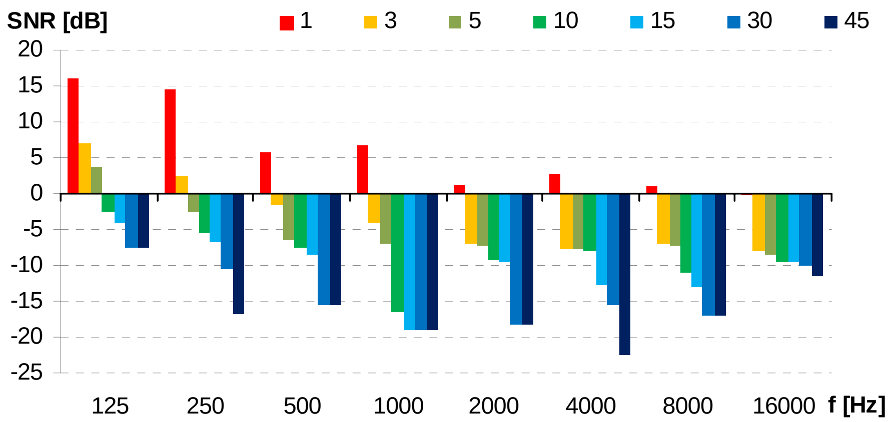

Fig. 9. Combined SNR_{dB} results for all examined frequencies. The recursive filtration was applied

5.2 One-third octave band noise measurement results

For that kind of measurements, the noise signals limited to one third octave band were used. The same numbers of test signals and presenting methodology were applied. In such case, the recursive filtration was not used. In Fig. 10 the example results for one third octave band noise, centered at 1000 Hz were shown. The black line was used to mark the averaged angle error for switched off the frequency correction and the blue line was obtained for switch on the frequency correction in the conditioning unit. The background noise level was equal to 45 dB SPL. The computed angle errors in comparison to pure tone examination are relatively similar. In Fig. 11 the combined SNR_{dB} results for all examined frequencies were presented.

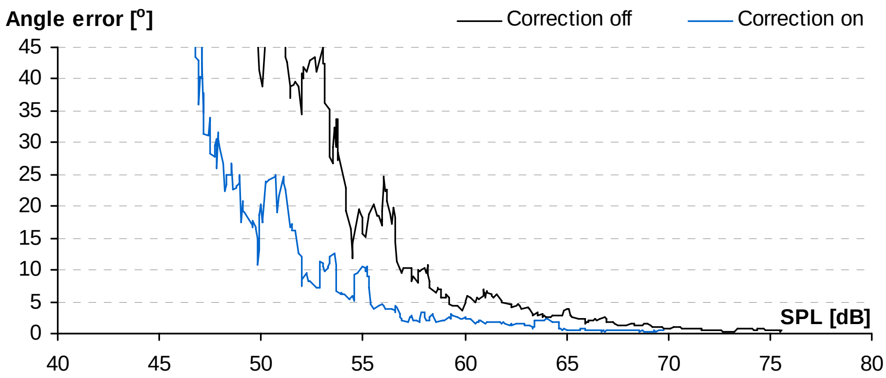

Fig 10. Example results for one third octavo band noise. Centre freq. equal to 1000 Hz

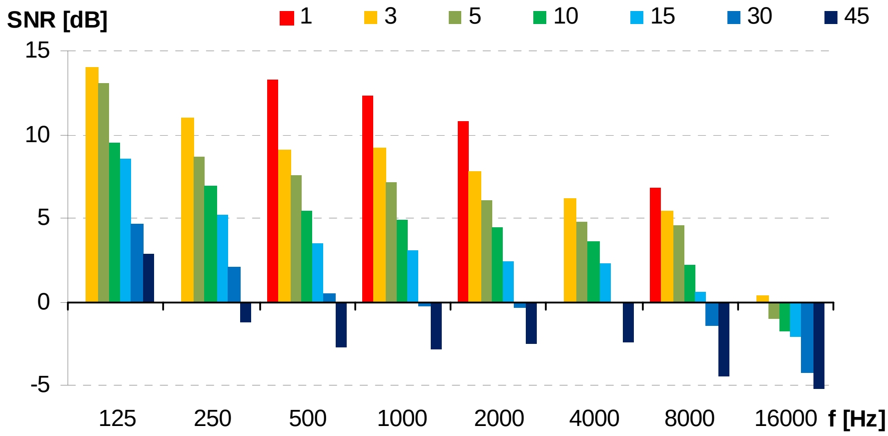

Fig. 11. The combined SNR_{dB} results for all examined frequencies

5.3 The impulsive sounds measurement results

In acoustic radar examinations, several kinds of impulsive sounds were used. During first session the noise-like burst for different time length was used. The impulse length was equal to respectively: 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384, 32768 samples. It corresponds to time periods from 0.0007s to 0.6827s. The next signal was based on 4000 Hz tone burst with the same sample lengths. The level of that signals was constant and was 30 dB greater than the background noise (45 dB SPL). The results obtained for the particular kind of tests were presented in Fig. 12. For the tonal burst the recursive filtration was also applied (blue line).

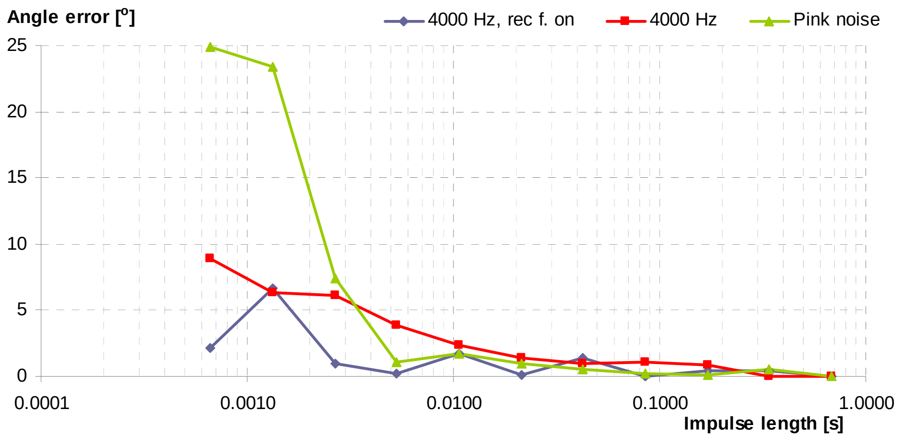

Fig. 12. Example results obtained for different kind of impulsive sounds. Noise and tonal burst with different length were used

Another kind of impulsive test signal employed 4000 Hz. It has 4096 sample length and its amplify was decreased by 3 dB in 12 steps from SNR_{dB} = 27 to SNR_{dB} = -6. The obtained results were presented in Fig. 13. The recursive filtration was also applied (blue line).

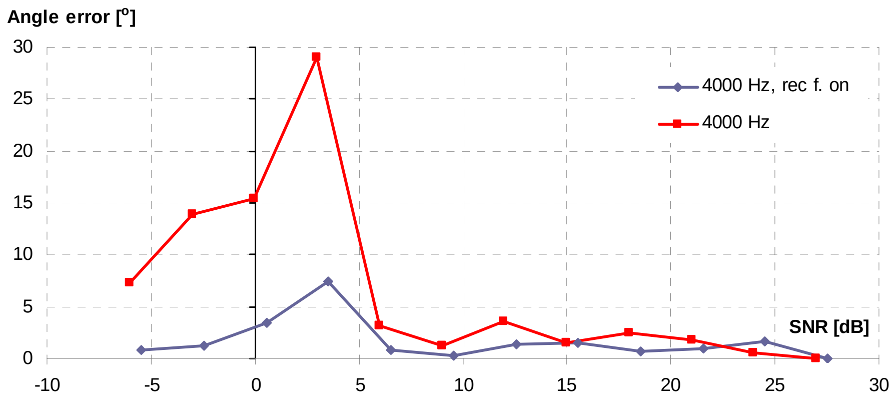

Fig. 13. Results obtained for impulse with different SPL level

5.4 PTZ camera control

Base on the information about the direction of the given sound event occurrence, the PTZ digital camera was used to capture the motion images of the field, where that event took place. Even the angle error estimation about 30° could be enough to effectively perceive the whole analyzed situation and can help to assess it correctly.

6 Conclusions

A concept and testing results of the passive acoustic radar were presented in the paper. Diverse type of test signals were used. Taking the obtained results of the realized experiments into consideration it was ascertained that even the inconsiderable value of the signal to noise ratio was sufficient to localize sound source suitably (SNR_{dB} near to 0 dB). The application of the recursive filtration can significantly improve sensitivity and accuracy of the acoustic radar (SNR_{dB} below -10 dB for tonal components). Such a kind of filtration can be used to discriminate between multiple sources. Examinations using impulsive sound were indicated that even extremely short and relatively quiet impulses could by properly detected and localized. Moreover, the automatic and continuous tracking of the selected sound source movement in real time is also possible. Additional procedures such as: sound source classification module or automatic control of the digital PTZ camera can be used to extend the usefulness of the presented device. The proposed device can significantly improve the functionality of the traditional surveillance monitoring systems.

Acknowledgments

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