




Acoustic Localization of Aerial Objects and Practical Evaluation of its Accuracy

S. A. Naida, Dr.Sc.(Eng.), Prof.,  [0000-0002-5060-2929](https://orcid.org/0000-0002-5060-2929)

O. I. Drozdenko, Dr.Sc.(Eng.), Assoc.Prof.,  [0000-0001-6647-1428](https://orcid.org/0000-0001-6647-1428)


P. V. Popovych, PhD, Assoc.Prof.,  [0000-0002-1572-3127](https://orcid.org/0000-0002-1572-3127)

K. S. Drozdenko, PhD, Assoc.Prof.,  [0000-0002-7653-600X](https://orcid.org/0000-0002-7653-600X)

O. I. Nyzhnyk, PhD,  [0000-0001-9170-8597](https://orcid.org/0000-0001-9170-8597)

Ya. I. Starovoit, PhD,  [0000-0003-0827-1633](https://orcid.org/0000-0003-0827-1633)

Department of Acoustic and Multimedia Electronic Systems <https://ames.kpi.ua/>

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"  [00syn5v21](https://www.researchgate.net/publication/359830100syn5v21)
Kyiv, Ukraine

Abstract— The active use of aerial objects creates a need for passive detection methods. This paper presents an experimental study of an automated acoustic hardware and software system based on the five-channel microphone array. Field tests were conducted in open terrain under conditions of background noise and wind. It is shown that the system provides stable determination of angular coordinates at distances up to 60 m, while a decrease in stability is observed at 80 m. The achieved accuracy of angular coordinate determination is 2–5°. It has been established that at short distances, the GPS error can cause significant angular uncertainty that exceeds the error of the acoustic system, limiting its use as a reference standard. The obtained results confirm the feasibility of application of the acoustic methods and identify the directions for the further development of acoustic localization systems.

Keywords — acoustic signal processing; sound source localization; microphone arrays; beamforming; direction of arrival (DOA) estimation; aerial objects; global positioning system (GPS)

1. INTRODUCTION

Detection of the aerial objects is complicated by low flight altitudes, small geometric dimensions, a small effective scattering surface, and the ability to operate in radio silence. Consequently, the role of passive surveillance methods capable of operating without emitting their own signals and without revealing the operator's position is growing [1-3].

One such approach is acoustic localization. The noise of propellers, electric motors, and aerodynamic disturbances forms a characteristic acoustic signature of an aerial object, which can be used to detect it and estimate its direction [1, 3]. The advantages of acoustic systems include relatively low cost, the ability to operate in complex electromagnetic environments, and compatibility with other sensor channels [2]. The disadvantages include sensitivity to weather conditions, non-stationary background noise, and spectral variability of the signal [4, 5].

In the literature, the problem of sound source localization (SSL) for the aerial objects is studied both from the perspective of classical massive processing

algorithms and using machine learning. Reviews note the high effectiveness of beamforming methods using delayed signal summation, such as MUSIC, SRP-PHAT, and GCC-PHAT, in cases where the signal-to-noise ratio is acceptable and the array geometry suits the task at hand [1, 3, 7]. At the same time, most authors emphasize that real-world field conditions significantly complicate the situation [2, 5]. Cases involving wind noise, natural background noise, and extraneous impulse sources are particularly challenging [2, 4]. For compact arrays based on MEMS microphones, additional challenges arise regarding channel matching, synchronization accuracy, and frequency band selection [7, 8]. Studies of the spectral characteristics of multi-rotor platforms show that the most informative frequency ranges are between several hundred Hz and several kHz, but the specific limits depend on the platform size, operating mode, and observation distance [3, 9].

A separate area of research involves the application of machine learning methods to improve localization stability under low SNR conditions. In particular, the use of deep neural networks allows for more stable direction



determination even in the presence of complex background noise [4, 10].

A significant gap in many studies is the lack of comparative analysis of the accuracy of the position of aerial objects and the readings of acoustic localization systems. Comparisons are often made with GPS or other navigation systems without evaluating their impact on angular error. This approach has fundamental importance, since GPS is frequently used as a reference during field tests, although its own accuracy may be insufficient for comparison at short distances [3, 5].

This paper discusses a prototype of an automated acoustic hardware and software system for detecting aerial objects, as well as a correct interpretation of its accuracy, considering errors in navigation coordinates.

The goal of this work is to provide a theoretical and experimental justification for the ability to localize a small-sized aerial object using an acoustic system with a microphone array under real-world conditions, and to correctly correlate the obtained results with data from navigation sensors installed on the aerial object.

II. THEORETICAL FUNDAMENTALS OF ACOUSTIC LOCALIZATION

The system operates by estimating the time difference in the arrival of a sound wave at different microphones in the array. For a source located at a distance significantly greater than the size of the array, the wavefront can be approximated as flat. In this case, the time delay between two microphones depends on the inter-microphone spacing and the angle of incidence of the wave.

For practical implementation of delay estimation, it is advisable to use cross-correlation of signals. However, due to the non-uniform spectral composition of the aerial object's signal and background noise, ordinary correlation can yield unstable results. Therefore, a common approach involves phase-normalizing of the cross-spectrum. This enhances the role of phase relationships and reduces the influence of amplitude differences between channels.

There are several variants of the method, which differ in how they compute the cross-correlation functions. The method is based on the use of a microphone array, in which each microphone receives a signal from the source with a certain delay. The method is based on forming a directed power response using an array of N receivers and determining the direction of signal arrival (DOA) based on the position of its maximum. If the microphone coordinates are known, the time difference of arrival (TDOA) contains information about the source position. In the work [11], an approach is proposed based on determining the cross-spectra of pre-filtered signals followed by the application of the inverse

Fourier transform, which is implemented in a method called Steered Response Power with Generalized Cross-Correlation (SRP-GCC). The obtained result is interpreted as the total spatial acoustic power $P(\theta)$:

$$P(\theta) = \sum_{l=1}^N \sum_{q=1}^N R_{lq}(\tau_{lq}) \quad (1)$$

Expression (1), referred to as the beamformer, contains the sum of the GCC functions for all possible combinations of receiver pairs with indices l and q ($l = 1, 2, \dots, N; q = 1, 2, \dots, N$):

$$R_{lq}(\tau_{lq}) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \psi_{lq}(\omega) G_{lq}(\omega) \exp(j\omega\tau_{lq}) d\omega, \quad (2)$$

where $\psi_{lq}(\omega)$ is filter weighting function; $G_{lq}(\omega)$ is cross-spectra.

The beamformer (1) determines the control delay vector $\tau_{lq} = \tau_l - \tau_q$ based on the signal delays at the respective array receivers relative to the phase center for each spatial direction. The directional response power (1) in each direction is the sum of all pairwise GCC functions, time-shifted according to the control vector. The total sum also includes N autocorrelations, which correspond to the GCC values at zero delay. They contribute only a constant component, since they do not depend on the control delays. The maximum directed response power is achieved when these delays correspond to the actual direction of wave propagation.

To reduce the effect of reverberation, the SRP-GCC-PHAT (Steered Response Power with Generalized Cross-Correlation Phase Transform) method is used, in which PHAT filtering is applied in the frequency domain with the corresponding weighting functions:

$$\psi_{lq}(\omega) = 1/|G_{lq}(\omega)|. \quad (3)$$

Its popularity stems from its high noise immunity, ability to process wideband signals, and relative ease of implementation in multichannel systems. Practical implementation involves space discretization in the form of a grid of directions or coordinates. For each point, the delays and the correlation function are calculated.

In work [12], based on experimental studies of the direction-finding of several types of small aerial objects, it was shown that the SRP-GCC-PHAT method outperforms the classical TDOA approach in terms of both detection range and azimuth accuracy. In particular, it was established that the detection probability exceeds 50% at distances over 300 m.

At the same time, the SRP-GCC-PHAT method is characterized by significant computational complexity, since it operates in the frequency domain and requires the calculation of generalized cross-correlation for all



microphone pairs. To reduce computational costs, some authors propose combined approaches [13] that involve first determining the search area using the TDOA method, followed by refining the direction using SRP-GCC-PHAT.

The SRP-GCC and SRP-GCC-PHAT methods are fundamental algorithms for acoustic source localization using microphone arrays. They are widely used in tasks involving the determination of the direction of signal arrival and the spatial coordinates of the source. SRP-GCC utilizes the amplitude-phase information of the signal. Its accuracy decreases in the presence of noise. SRP-GCC-PHAT normalizes the spectrum and uses only phase information, which improves accuracy.

In practical processing, not only time delays but also the correct choice of frequency band is important. If the low-frequency region is heavily contaminated by wind noise, and the high-frequency region decays rapidly with distance, then the best information content can be provided by the mid-frequencies. This is why theoretical analysis must be combined with spectral analysis of real recordings.

III. EXPERIMENTAL SETUP AND MEASUREMENT PROCEDURES

Description of the Experimental Setup.

The experimental setup included:

- a prototype of an acoustic software and hardware complex for detecting the aerial objects (Fig. 1), consisting of a microphone array (1) (Fig. 2), a hardware unit for signal acquisition and processing (2), and a laptop with software for recording, processing, and visualizing the information (3);
- an SL-4033SD sound level meter for monitoring the sound pressure level at the location of the microphone array (Fig. 2);
- a signal source as a small aerial object.

The microphone array consists of 5 microphones. Microphones 1-3 are arranged in a horizontal plane in a circle. This arrangement forms the main aperture of the antenna for the azimuth position estimation of the sound source. The fourth microphone is positioned in the direction opposite the first microphone, i.e., at an angle of 180° relative to it. The fifth microphone is installed in the central part of the antenna. The presence of a central elevated microphone allows for additional analysis of the spatial structure of the acoustic field and can be used to estimate the vertical component of the wave arrival direction.

The use of identical microphones in all channels ensures the uniformity of the amplitude-frequency

characteristics of the measurement system and reduces errors associated with inter-channel differences between receivers.

A. Experimental Conditions.

Measurements were conducted under favorable weather conditions: air temperature $13-15^\circ\text{C}$, humidity $65-70\%$, wind from the north-west at $3-5\text{ m/s}$, sunny, no precipitation. The presence of moderate wind with gusts

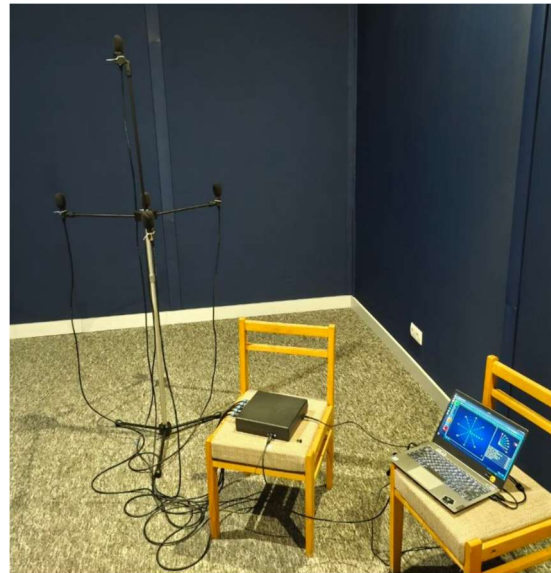


Fig. 1. Setup of a prototype acoustic hardware and software system in an anechoic chamber prior to field tests



Fig. 2. Arrangement of measuring equipment during field tests



is a principal factor for acoustic measurements, as wind affects both the background noise level and the stability of the signal's spectral and spatial characteristics. Natural acoustic interference was also present in the background, including the rustling of trees and bird sounds.

The antenna was mounted on the roof of a vehicle (Fig. 2), and its reference direction was oriented towards the north.

B. Experimental Methodology.

The location target was a small aerial object. During the experiment, the location target was positioned at various points relative to the antenna and activated in static positions. Separate recordings were made during the object's flights, which allowed for evaluation not only the accuracy of azimuth determination under stationary conditions but also the stability of the algorithms in dynamic mode.

A schematic representation of the antenna's position and the points at which the aerial object's location was recorded is shown on the test site map (Fig. 3).

In most recordings, the small aerial object remained stationary on a support, which helped to minimize the uncertainty associated with the source movement.

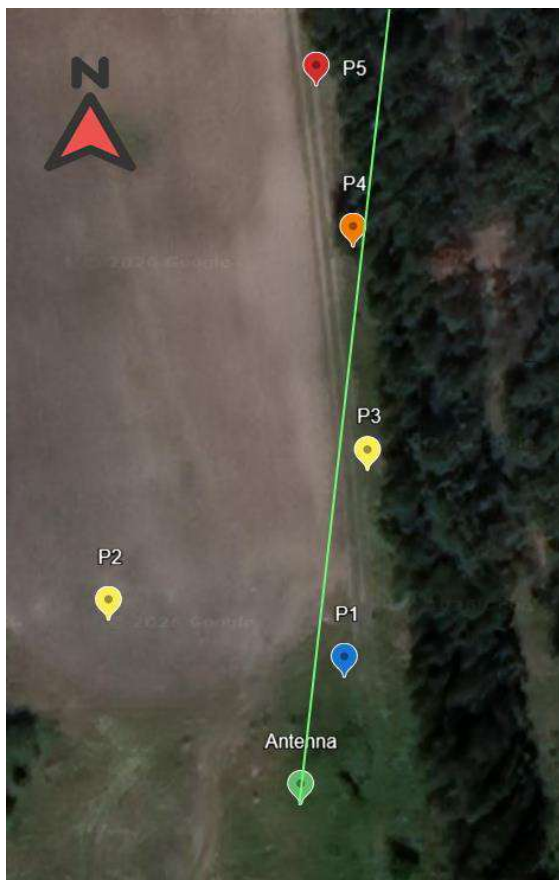


Fig. 3. Position of the antenna and reference measurement points

The distances to the aerial object for the various reference points P1-P5 were 20, 35, 40, 60, and 80 m, respectively, with a margin of error of ± 1 m. In parallel with the acoustic data, coordinates obtained by GPS receiver were recorded. Recordings were made under conditions of moderate wind with gusts, natural background noise, and bioacoustic interference.

IV. RESEARCH RESULTS AND THEIR ANALYSIS

The methodology for processing research results involved the construction of the azimuth distribution diagrams for background noise, calculation of the bearing patterns for reference points, analysis of the peak factor and spectral power density, and examination of the 1/3-octave signal levels of the aerial object at various distances.

An important initial condition for processing acoustic signals is the selection of the value of the speed of sound in air. Since the speed of sound depends on temperature, it is advisable to use a value calculated according to the actual experimental conditions rather than a fixed approximate value when processing the field recordings. The speed of sound in dry air can be estimated using the following approximate formula:

$$c \approx 331.5 + 0.6 T, \quad (4)$$

where c is speed of sound, m/s, and T is an air temperature, °C.

For the temperature value 15 °C, we obtain:

$$c \approx 331.5 + 0.6 \cdot 15 = 340.5 \text{ m/s.}$$

Therefore, it is advisable to use a speed of sound of 340.5 m/s in subsequent calculations. Using this value is more accurate for field measurements than using the reference value of 343 m/s, which corresponds to a temperature of 20 °C. Although the difference between these values is relatively small, for tasks involving the estimation of time delays between channels and the determination of azimuth, it can affect the accuracy of the result.

Equations (1-3) describe the SRP-GCC-PHAT algorithm, which served as the theoretical basis for the operation of the acoustic hardware and software complex.

Figures 4-6 show the indicator readings in the absence of drone sound (Fig. 4) and in its presence at various distances of 20 m (Fig. 5) and 60 m (Fig. 6). Fig. 4 shows that in the presence of only background noise, the indicator readings do not have a clearly defined maximum. This distribution of azimuths is caused by the presence of wind and other noise sources.

A. Results of Bearing Measurements at Control Points and the Effect of GPS Coordinate Errors on Azimuth Estimation.

We analyzed how GPS positioning error affects the azimuth calculated between the antenna and the drone. This is a key point, since even a GPS system that is quite accurate in metric terms may not be precise

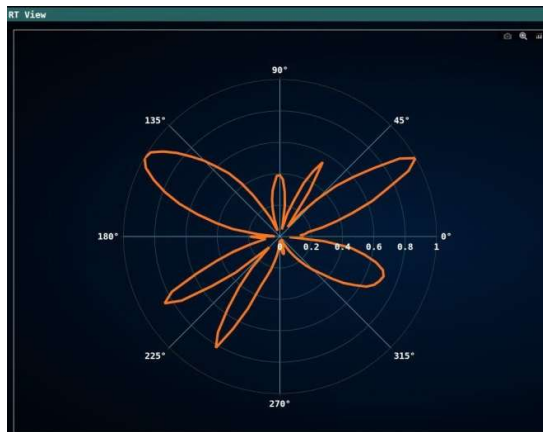


Fig. 4. Indicator readings for background noise.

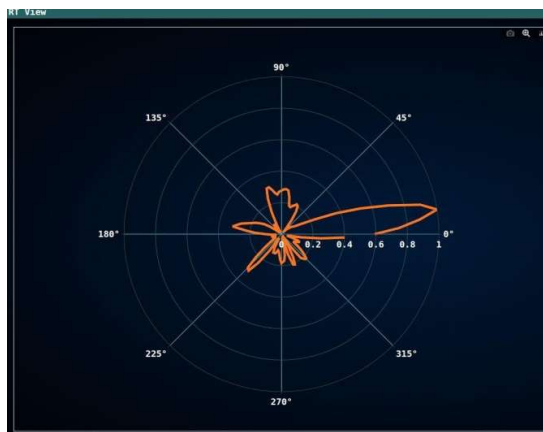


Fig. 5. Drone azimuth at point P1 (20 m)

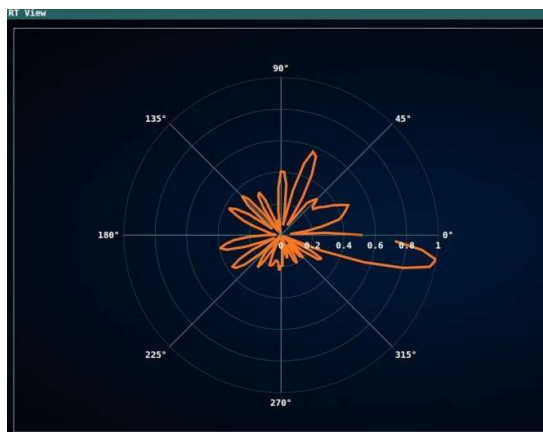


Fig. 6. Drone azimuth at point P4 (60 m)

enough for angular measurements at short distances. If the antenna and the drone are only 20-30 m apart, an error of a few meters in the coordinates of each point leads to significant uncertainty in the direction.

For point P1, located at 20 m from the antenna (Fig. 5), the system produced a well-defined maximum. In this scenario, the signal level of the aerial object is the highest, so from the perspective of the acoustic path, this is the most favorable case. At the same time, GPS uncertainty has the greatest impact on reference azimuth in this case. However, the coincidence of the acoustic estimate with the visual position of the aerial object speaks in favor of the system performance.

For point P2, located at 35 m, the main peak was approximately 291°. It agrees with the actual position of the aerial object on the map and is confirmed by visual observation during recording. For point P3 at 40 m, the azimuth value was 2 degrees, which also corresponds to the actual position of the aerial object.

At point P4 (Fig. 6) at 60 m, the peak remains distinct but becomes less pronounced than at shorter distances. At point P5, 80 m away, a broadening of the peak and a decrease in stability are observed. This is consistent with a reduction in the excess energy of the aerial object's signal relative to the background. Finally, it can be concluded that the system operates reliably up to 60 m and maintains functionality at 80 m due to proper spectral sampling and algorithmic processing.

A comparison of the field background with a laboratory recording of relative silence showed that the field environment has a significantly higher noise level. In terms of average sound pressure level, the background in the field was approximately 14-18 dB higher, and in terms of RMS value, it was several times higher. This means that the localization algorithm operates not in an abstract noise model, but in a real environment where the interference level varies in time and space.

The spectral power density of the field background exhibits a pronounced low-frequency dominance, characteristic of wind and distant broadband sources. In addition, differences in spectral shape are observed between the array channels, indicating spatial heterogeneity of the interference field. This is important for further development, since methods that do not consider inter-channel relationships may prove to be insufficiently robust.

B. Comparison Of the Results Obtained Using Acoustic System with Coordinate Sensors on Aerial Object.

The results obtained by the acoustic system were compared with data from coordinate sensors installed on the aerial object. A summary of the tests shows that the acoustic system provides azimuths at all control



TABLE 1. COMPARISON OF THE ANGULAR UNCERTAINTY OF THE GPS AZIMUTH AND THE ERROR IN ACOUSTIC POSITIONING

Point	Distance, m	Estimate of GPS azimuth error, °	Estimate of acoustic error, °
P1	20±1	up to 37	2-3
P2	35±1	up to 24	3-5
P3	40±1	up to 20	2-4
P4	60±1	up to 12	3-4
P5	80±1	up to 9	up to 5

points that are consistent with the experiment's geometry. At the same time, the GPS coordinate data provides only an approximate angular reference, the accuracy of which depends significantly on the distance between the antenna and the drone.

At short distances of 20-30 m, the possible range of error for the GPS azimuth is significantly wider than the spread of acoustic estimates (Table 1). This means that, in practical terms, the acoustic system is no less and, in some cases, even more informative regarding the direction of the drone than GPS positioning. As the distance increases, the role of coordinate error decreases; however, even at 60–80 m, it remains significant.

The obtained result is important not only for evaluating a specific prototype but also for the methodology of further testing. If the accuracy of the acoustic system needs to be verified to within a few degrees, the reference coordinates must be obtained using optical tracking or another method with better spatial accuracy. Otherwise, the reference error may mask the system's true potential.

CONCLUSIONS

1. The operational capability of a prototype automated acoustic hardware and software system for the acoustic localization of small airborne objects using a microphone array and the SRP-GCC-PHAT algorithm has been experimentally confirmed under real-world field conditions in the presence of background noise and wind interference.
2. It has been established that the system provides stable azimuth determination at distances up to 60 m, whereas at distances up to 80 m, localization is maintained but is characterized by reduced stability due to a decrease in the signal-to-noise ratio.
3. It has been shown that when using GPS as a reference coordinate source at short distances (20-40 m), significant angular uncertainty arises, which may exceed the inherent error of the acoustic system. This indicates the limited

suitability of GPS for verifying high-precision acoustic localization in the near field.

4. The accuracy of angular coordinate determination achieved by the system is 2–5° in the studied range of distances, confirming its effectiveness for the task of rapid determination of the direction of an aerial object.
5. The obtained results confirm the feasibility of further development of an automated acoustic hardware and software complex as a component of systems for the detection and localization of aerial objects.

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REFERENCES

- [1] S. F. Chevtchenko, B. J. Rodriguez, R. F. do Vale, A. Soti, Y. Bethi, N. Ibnul, A. Marcireau, M. R. Azghadi, A. Wabnitz, and S. Afshar, "Drone-based sound source localisation: A systematic literature review," *IEEE Access*, early access, 2025, doi: [10.1109/ACCESS.2025.3572478](https://doi.org/10.1109/ACCESS.2025.3572478).
- [2] Z. Ghouli, "Passive acoustic detection and localization of drones using MEMS microphones and machine learning," *Acta Acustica*, vol. 10, p. 12, 2026, doi: [10.1051/aacus/2026008](https://doi.org/10.1051/aacus/2026008).
- [3] S. Wu, Y. Zheng, K. Ye, H. Cao, X. Zhang, and H. Sun, "Sound source localization for unmanned aerial vehicles in low signal-to-noise ratio environments," *Remote Sensing*, vol. 16, no. 11, Art. no. 1847, 2024, doi: [10.3390/rs16111847](https://doi.org/10.3390/rs16111847).
- [4] A. Toma, "Deep acoustic learning on unmanned aerial vehicles for real-time human and drone detection," *Integrated Computer-Aided Engineering*, vol. 33, no. 2, pp. 182–199, Feb. 2026. doi: [10.1177/10692509261417106](https://doi.org/10.1177/10692509261417106).
- [5] B. J. Rodríguez, S. F. Chevtchenko, M. H. Martínez, Y. Bethi, and S. Afshar, "Acoustic imaging for UAV detection: Dense beamformed energy maps and U-Net SELD," *arXiv preprint*, arXiv:2508.00307, 2025. doi: [10.48550/arXiv.2508.00307](https://doi.org/10.48550/arXiv.2508.00307)
- [6] J.-M. Valin, F. Michaud, J. Rouat, and D. Létourneau, "Robust sound source localization using a microphone array on a mobile robot," in *Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems (IROS)*, 2003, pp. 1228–1233. doi: [10.1109/IROS.2003.1248813](https://doi.org/10.1109/IROS.2003.1248813)
- [7] D. Pavlidi, M. Puigt, A. Griffin, and A. Mouchtaris, "Real-time multiple sound source localization using a circular microphone array based on single-source confidence measures," in *Proc. IEEE Int. Conf. Acoustics, Speech and Signal Processing (ICASSP)*, 2013, pp. 260–264. doi: [10.1109/ICASSP.2012.6288455](https://doi.org/10.1109/ICASSP.2012.6288455)
- [8] J.-M. Valin, F. Michaud, and J. Rouat, "Robust localization and tracking of simultaneous moving sound sources using beamforming and particle filtering," *Robotics and Autonomous Systems*, vol. 55, no. 3, pp. 216–228, 2007. doi: <https://doi.org/10.1109/ICASSP.2012.6288455>
- [9] I. An, D. Lee, B. Jo, J.-W. Choi, and S.-E. Yoon, "Robust sound source localization considering similarity of back-propagation signals," *arXiv preprint*, arXiv:1902.09179, 2019. doi: [10.48550/arXiv.1902.09179](https://doi.org/10.48550/arXiv.1902.09179)










- [10] J.-M. Valin, F. Michaud, and J. Rouat, "Robust 3D localization and tracking of sound sources using beamforming and particle filtering," in Proc. IEEE Int. Conf. Robotics and Automation (ICRA), 2006, pp. 302–307. doi: [10.1109/ICASSP.2006.1661100](https://doi.org/10.1109/ICASSP.2006.1661100)
- [11] J. H. DiBiase, *A High-Accuracy, Low-Latency Technique for Talker Localization in Reverberant Environments Using Microphone Arrays*, Ph.D. dissertation, Div. Eng., Brown Univ., Providence, RI, USA, May 2000.
- [12] A. Sedunov, H. Salloum, A. Sutin, N. Sedunov, and S. Tsyuryupa, "UAV passive acoustic detection," in Proc. IEEE Int. Conf., 2018, pp. 1–6. doi: [10.1109/THS.2018.8574129](https://doi.org/10.1109/THS.2018.8574129)
- [13] A. Astapov, P. Ehala, S. Berdnikova, and J. Preden, "Direction of arrival estimation based on SRP-PHAT for compact microphone arrays," in Proc. Int. Conf. Digital Signal Processing (DSP), 2015, pp. 1–6. doi: [10.1109/SAM.2018.8448492](https://doi.org/10.1109/SAM.2018.8448492)

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Акустична локалізація повітряних об'єктів та практична оцінка її точності

С. А. Найда, д-р техн. наук, проф.,  [0000-0002-5060-2929](https://orcid.org/0000-0002-5060-2929)
О. І. Дрозденко, д-р техн. наук, доц.,  [0000-0001-6647-1428](https://orcid.org/0000-0001-6647-1428)
П. В. Попович, канд. техн. наук, доц.,  [0000-0002-1572-3127](https://orcid.org/0000-0002-1572-3127)
К. С. Дрозденко, канд. техн. наук, доц.,  [0000-0002-7653-600X](https://orcid.org/0000-0002-7653-600X)
О. І. Нижник, канд. техн. наук,  [0000-0001-9170-8597](https://orcid.org/0000-0001-9170-8597)
Я. І. Старовойт, канд. техн. наук,  [0000-0003-0827-1633](https://orcid.org/0000-0003-0827-1633)

Кафедра акустичних та мультимедійних електронних систем <https://ames.kpi.ua/>
Національний технічний університет України
«Київський політехнічний інститут імені Ігоря Сікорського»  [00syn5v21](https://doi.org/10.1007/978-3-319-00syn5v21),
Київ, Україна

Анотація—Через активне використання повітряних об'єктів виникає потреба в пасивних засобах їх виявлення. У роботі проведено експериментальне дослідження автоматизованого акустичного програмно-апаратного комплексу на основі мікрофонного масиву з п'яти каналів. Проведено натурні випробування в умовах відкритої місцевості за наявності фоновому шуму та вітру. Показано, що система забезпечує стійке визначення кутових координат на відстанях до 60 м, тоді як на 80 м спостерігається зниження стабільності. Досягнута точність визначення кутових координат становить 2–5°. Встановлено, що на малих дистанціях похибка GPS може формувати значну кутову невизначеність, яка перевищує похибку акустичної системи, що обмежує його використання як еталону. Отримані результати підтверджують доцільність застосування акустичних методів та визначають напрями подальшого розвитку систем акустичної локалізації.

Ключові слова — обробка акустичних сигналів; локалізація джерела звуку; мікрофонні масиви; формування променя; оцінювання напрямку приходу (DOA); повітряні об'єкти; глобальна система позиціонування (GPS).

