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ADVANTAGES AND DISADVANTAGES OF VECTOR SENSORS COMPARED TO CLASSICAL ACOUSTIC SENSORS AND ACOUSTIC ANTENNAS

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Abstract. *The report examines the characteristics, advantages and disadvantages of vector acoustic sensors used in recent years in civil and military information systems for the detection, localization and classification of various types of targets and noise sources with high dynamics of emitted signals. A comparison with classical acoustic sensors and discrete acoustic antennas is given. Conclusions and recommendations are made. They are based on a review of publications and experiments.*

Key words: *acoustic sensors, weapon systems, battlefield detection*

1. INTRODUCTION

Increasing the efficiency of all acoustic systems is directly related to improving the signal/noise ratio [1,2]. In this regard, one of the most important elements of these systems is the acoustic sensor, which perceives and converts information. It can be a single sensor or a group of sensors constructed as an antenna array. In some cases, groups of sensors located at long distances are also grouped to obtain as large a base as possible. All subsequent processing of the signals and ultimately the adoption of one or another solution depends on the characteristics of the sensor.

It is clear that obtaining as much information as possible about the acoustic field at any set spatial volumes can be done by the optimal placement and increase in the number of

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pressure sensors or by additionally placing receivers of the first or higher order. This allows us to obtain both the sound pressures and their gradients, bi-gradients, etc.

A few decades ago, sound pressure gradient receivers were used for the first time in certain acoustic equipment in a one-dimensional, two-dimensional and three-dimensional version. The three-component sound pressure gradient receiver whose sensors are located along the three orthogonal axes with one phase center is commonly referred to as the vector receiver [3,4].

The main advantage of a vector receiver is that it can determine the location of the sound source from a point without the need for an antenna configuration from multiple pressure receivers. This is particularly important for acoustic signals and noises in the low-frequency audible and near and far infrasonic ranges. If a classic discrete antenna array is used, the antenna aperture would be extremely large. In some cases, as in sound-ranging systems, it is necessary to use acoustic groups of sensors spread in space at a distance of hundreds of meters [5] or even kilometers with additional time delay processing and other characteristics of the received signals (most often pulsed).

2. CLASSICAL ANTENNA SYSTEMS

One way to improve the signal/noise ratio is to use acoustic antennas, most often in the form of antenna arrays. It is generally known that when hypothetical point acoustic transducers are located at a distance of less than or equal to half a wavelength $d \leq \lambda/2$, the directivity characteristic is equivalent to that of a continuous antenna with the same aperture. It is important to note that the directivity diagram is obtained for the far field of the antenna, where the intensity of the sound drops inversely with the square of the distance, that is, by a spherical law. The district is called the Fraunhofer zone. For a flat emitter, the distance r to its near limit is determined by the formula [1,2]:

$$r \sim \frac{d^2}{\lambda} \tag{1}$$

where λ is a wavelength in meters, d is the largest linear emitter size.

One of the most important parameters of the antenna is the normalized directivity diagram, which is found as the ratio of the spatial directivity diagram A (α, φ) to its meaning in the direction of maximum pressure A (0.0):

$$R(\alpha, \varphi) = \frac{A(\alpha,\varphi)}{A(0,0)} \tag{2}$$

It is obvious that the meaning of the normed directivity diagram is always less than or equal to one.

The concentration coefficient is another very important parameter. It is obtained as a ratio of the intensity of the axis of the antenna to the intensity at the same point of a non-directional emitter at the same power of the two instruments. Its approximate meaning can be determined by the formula:

$$\gamma = \frac{4\pi S}{\lambda^2} \tag{3}$$

From the above ratios, it can be concluded that as the frequency of the sound wave decreases, the dimensions of the antenna at the same set directionality increase. The problem is particularly large with low sound and infrasonic frequencies. As is known, the absorption of the energy of acoustic waves is proportional to the square of their frequency [1]. For example, a sound wave with a frequency of 1000 Hz loses 90 % of its energy at a distance of 7 kilometers at sea level, if the frequency is 1 Hz, this distance is 3000 kilometers [5]. In addition, firing conventional fire systems creates extremely wide-spectrum noise that contains infrasound, sound and ultrasound. Therefore, acoustic direction finders built according to the classic scheme use a measuring base with a length of several hundred meters and pressure sensors. Different types of antenna arrays are commonly used to study battlefield acoustics in modern acoustic information systems [5,6,7]. They must form a directional beam over a wide frequency range. In principle, two sound receivers are required to determine the direction of the sounding target. However, two more receivers are needed to determine the coordinates of the target (classical principle of triangulation). A third pair of receivers is used for greater accuracy. A third receiver (microphone) can be placed in the center of the acoustic base. Accuracy increases even more.

3. VECTOR RECEIVERS

The one-dimensional velocity sensor measures the speed of air movement through two small, resistive strips of platinum that heat up to 220°C [8,9], Fig. 1. In acoustics, this movement of air is called the oscillation velocity of particles. When the air passes through the strips, the first strip cools a little and therefore the air is heated. The second strip is therefore cooled with slightly heated air and cooled less than the first conductor. A temperature difference occurs in the wires and causes a difference in their electrical resistance. This results in a voltage difference that is proportional to the particle velocity and the effect is directional: when the direction of the airflow changes, the temperature difference will also change. In the case of a sound wave, the airflow through the strips alternates depending on the waveform and thus the direction can be determined. In Fig.1, a three-dimensional vector sensor is shown. For comparison, a match was photographed together with him. The right panel shows a similar sensor mounted on the Colt C8 along with a miniature microphone, as well as a Microflown-Avisa shot detection system.

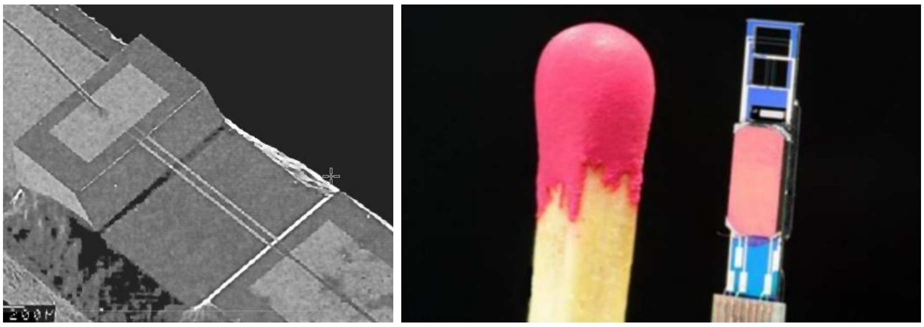

Fig. 1 One-dimensional vector sensor (particle velocity sensor) - the left panel. A three-dimensional vector sensor was photographed on the right panel. In comparison, a match was photographed with him

Fig. 2 A three-dimensional vector sensor mounted on the Colt C8 along with a miniature microphone [7] is shown on the left panel. On the right panel is the Ground-Based Gunshot Localization System – GBGLS, http://microflown-avisa.com/products/ground-based-gunshot-localisation/, equipped with a similar sensor [8]

4. SOME RESULTS AND CONCLUSIONS

Over the past year, our team has taken acoustic measurements of various types of conventional weapon systems. The experiments were conducted at the Belyakovets shooting range, near the city of Veliko Tarnovo in June and at the Markovo training ground, near the city of Shumen, in September.

To obtain the raw acoustic signal, a Type 4193 wideband measuring microphone, combined with a classic Type 2669 low noise preamplifier and a compact 35608 Bruel&Kjaer data acquisition module, was used. In addition, an acoustic antenna array with 30 microphones of the same company was also used - Figs. 3 and 4.

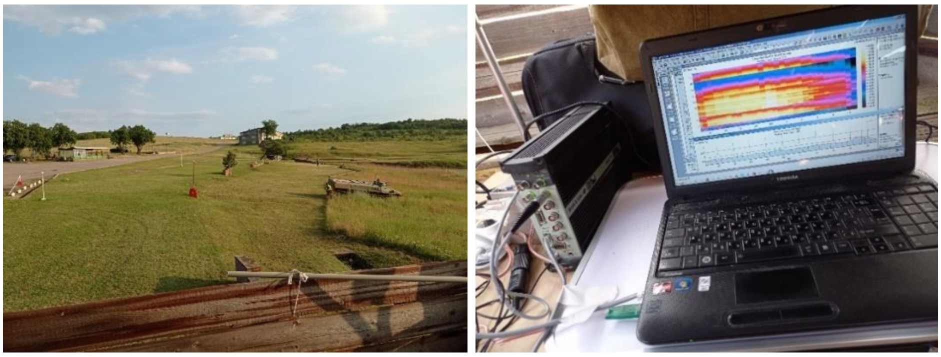

Fig. 3 On the left panel: Belyakovets shooting range; on the right panel: a typical measurement screen with a compact data collection module 35608 Bruel&Kjaer

Fig. 4 Conducting measurements during a complex tactical exercise in the village of Belyakovets. The antenna array of a Bruel&Kaer acoustic camera is visible

Fig. 5 Conducting demonstration shootings at the range in the village of Markovo, 24-26.09.2024. On the left panel 152 mm howitzer D20, on the right panel 122 mm SAU Gvozdika

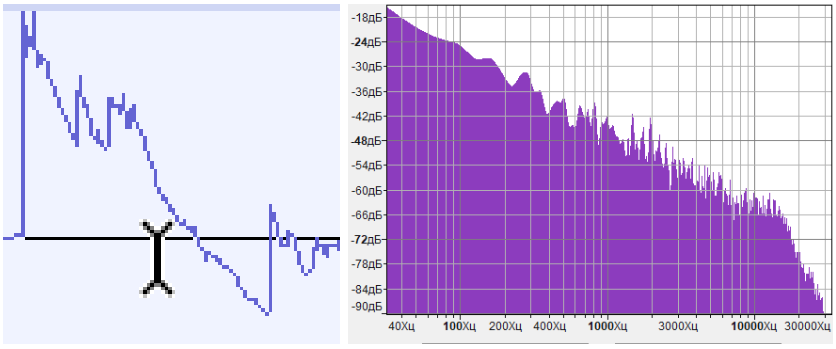

Fig. 6 Conducting demonstration shootings at the range in the village of Markovo, 24-26.09.2024. On the left panel, a recording of the muzzle wave of the 122 mm Gvozdika self-propelled gun, on the right panel, the spectrum of the shot

Explosive propelled weapons produce their characteristic sound as a result of the rapid expansion of gases at the end of their barrel, formally known as muzzle blast. The second component is the shock wave created by supersonic projectiles. It is commonly called N-wave due to its characteristic geometry and, unlike the muzzle blast, it has a local influence since it only appears at distances close enough to the trajectory of the projectile. In close-range recordings, ground reflections from both muzzle blasts and shock waves, along with the sound produced by the firing mechanism of the weapon, are most likely overlapped with the direct signal. From the spectrum of the shot shown in Fig.6 it is seen that, as might be expected, the acoustic energy is concentrated in the region of the low and infrasonic frequencies.

The acoustic situation on the battlefield has extreme, complex and multifaceted parameters. Different weapon systems, vehicles and the human factor create high-intensity noises and sounds, a large dynamic and frequency range. In addition, they are of different duration, directionality and spectral composition. The frequency range extends from infrasound at near zero frequency to ultrasound of several tens of kilohertz. This necessitates the use of complex acoustic and seismic systems for the detection, localization and classification of sources.

As emphasized above, the expertise of the authors who for many years designed, constructed and analyzed acoustic and hydroacoustic equipment allows us to draw the following important conclusions:

- acoustic sensors are at the beginning of the signal processing system. Therefore, the quality of the entire system depends on its parameters;
- sensors must have a maximally simplified construction, small dimensions and mass and be resistant to climatic and other effects;
- sensors must be easily maskable;
- the main advantage of acoustic detection systems is that they are passive;
- modern technologies make it possible to construct microphones with a sufficiently wide bandwidth - from infrasonic to ultrasonic frequencies;
- recent technological advances allow the creation of miniature acoustic vector sensors that make it possible to replace discrete acoustic antenna arrays that take up a lot of space and are easily detectable by the potential opponent.

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