UDC 623.4/519.2+004.75
DOI: 10.20535/SRIT.2308-8893.2025.4.02

THE RESULTS OF THE MULTI-POSITION SURVEILLANCE SYSTEM'S EFFICIENCY, DEPENDING ON THE LOCATIONS OF ITS SENSORS, USING ADDITIONAL DATA PROCESSING

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Abstract. The efficiency of a multi-position system depends on the realization of its structure—how many elements it includes, where they are located, and how the environment and terrain influence its operation. The paper is dedicated to data processing in a multi-position surveillance system as an additional option, leveraging the in-between big data from the system's elements. A sufficient number of numerical data generated by the multi-position system and its elements–sensors–allows the use of statistical methods and models from machine learning or deep learning. The ontology for quality estimation of the multi-position system, depending on its configurations, is proposed. The results of the distributions of detected events are presented in graphical forms that allow statistical evaluation of the distributed data. Our findings allow us to ensure the efficiency of a multi-position system in an unpredictable, variable environment by reconfiguring it when it offers better capabilities.

Keywords: data processing, surveillance, detection, multi-position system, system-of-systems, efficiency.

INTRODUCTION

Being multidisciplinary, science is able to cover different areas simultaneously. Our research corresponds to this feature — there are several independent areas from System Engineering, Estimation theory, Geospatial Intelligence, Big Data Processing, Machine Learning (ML), Deep Learning (DL). For example, there is a well-known problem of accuracy in Detection theory that has limits when using its methods and algorithms, but due to collaborating with methods and algorithms from other scientific fields such limits would be overcome. Another example is a problem of detection system's design to be optimized for unpredictable and variable environment. The mentioned problem takes place for multi-positional detection system. It is a very difficult mission to define the effective structure of multi-positional detection system especially during warfare. This research investigates a method for evaluating a detection system's structure based on its operational results, — the results for in-between data (not the results of direct detection) from elements of multi-positional detection system are presented. As usual, any system produces a great part of in-between data that could be additional information when it is necessary to improve the efficiency of the system. The volume of in-between data is enormous, so it makes possible to use Big Data Processing, ML or DL. So, the data preprocessing and statistical analysis were used to present the detection results on additional grid coordinate system and to make a statistical evaluation for the data.

PROBLEM STATEMENT

The theory and practice of developing multi-position systems have been well-studied for a long time [1]. The problem to be solved is formulated as follows. Having some specific uncertain environment, the scientific and technical task is to register certain changes in this environment using technical solutions implemented in the systems. There are many areas of application for such a problem — studying nature and space, medicine, monitoring the security situation at infrastructure facilities, military monitoring systems [2]. Obviously, there are different well-known kinds of passive multi-position surveillance system (MPSS) for acoustic location, GPS tracking, imagery intelligence, seismic reflection, signals intelligence, thermal imaging, underwater acoustics, video surveillance, wireless tracking etc. The physical nature for each method is unique, but there are some common similarities: 1) waves (signals); 2) a set of distributed synchronous sensors; 3) a great volume of measurement results — the datasets.

Therefore, if a certain system has already been developed and is functioning, then the main next task is to ensure the best (optimal) way to process information (data, signals).

In modern systems, whether specialized functional systems [3; 4], complex multi-profile systems [5], or systems of systems [6] — signal and information processing occurs across multiple stages. These processes are diverse and often complementary, but the specific way used to identify them is less critical than their integration. Regardless of the system's architecture, an "integrated" processing pipeline inevitably incorporates Big Data analytics or the processing of large volumes of homogeneous data alongside other methods, algorithms, and software solutions [7].

The purpose of the research. Our goal is to make a qualitive analysis of the efficiency of multi-position system using data preprocessing and statistical data analysis to change its configuration improving the detection possibilities.

The general aspects of a configuration of a multi-position surveillance system

A passive MPSS with a set of typical sensor posts (SPs) for terrain monitoring and/or control is done. The configuration of MPSS is the combination of all SPs on the terrain in some grid-like projection. The example of configuration is on the Fig. 1, where from 1 to 9 are the typical SPs being synchronous in a passive MPSS. The SPs are distributed on the terrain in some way, on the picture it is used a distance of 1.5 km between two sensors in the first (upper) line of the configuration and a distance of 1 km between first and second (below) lines. The MPSS base line is the distance between two utmost SPs (here are SP1 and SP6). The sensitivity for a MPSS means the possibility to detect some signals (on the potentially attainable distance for the signal with some defined level (power)). Here the range area is a circle of 25 km in radius (for the optimal conditions).

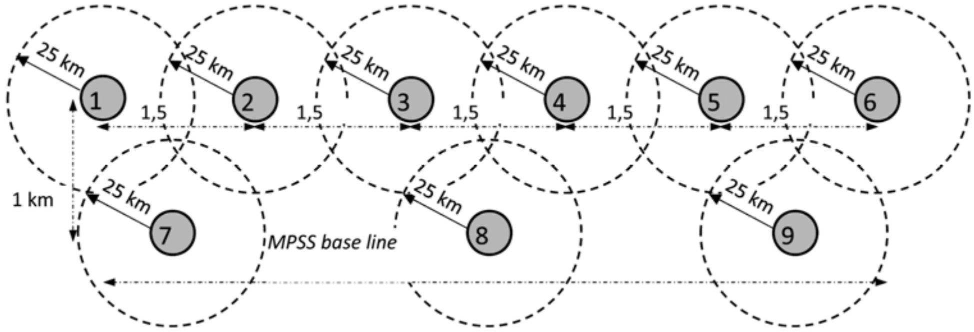


Fig. 1. The example of possible configuration for a typical MPSS (the sketch is not at scale)

As it is clear from the Fig. 1, the potential area of MPSS's sensitivity may have some form with 25 km in depth for any side direction from the utmost sensors. The two lines in MPSS's configuration allow for the determination of the Area of Interest (AoI) by excluding, for example, signals from back (useless) directions. Such a task is typical in security or military applications where both friendly (allied) and adversary forces are present. The optimal AoI for some general configuration and conditions should have some right form (Fig. 2). The orthogonal line (OL) to base line shows a main direction of AoI (main surveillance angle (MSA) is an angle between OL and main danger direction (MDD)).

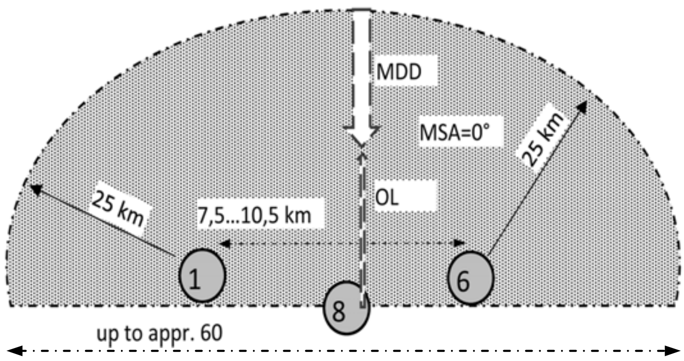


Fig. 2. The form of the MPSS's sensitivity (dotted area)

A note: 1 — The typical sensors 2–5 from the upper line (Fig. 1), sensors 7 and 9 from the below line are missing here to have a simple picture. MSA here is 0 degree that is the best for AoI

In real-world conditions, an ideal AoI does not exist. The first reason for it is the terrain features where the MPSS's configuration is set — there are no possibilities to establish typical sensors on the straight line (or two lines) with even distance between sensors. Further, the real terrain is characterizing with relief and natural or artificial coverings — the such reality effects on the MPSS's sensitivity. The second reason is some secure restrictions which are inevitable for warfare. The technical challenges (such as the problems with a sensor's operating or with some kind of destroying in warfare) are the next factor that makes an effect on the MPSS. So, the real MPSS's configuration has a non-optimal decision with a smaller number of sensors in a usage (Fig. 3) and it results in a less achievable AoI (Fig. 4).

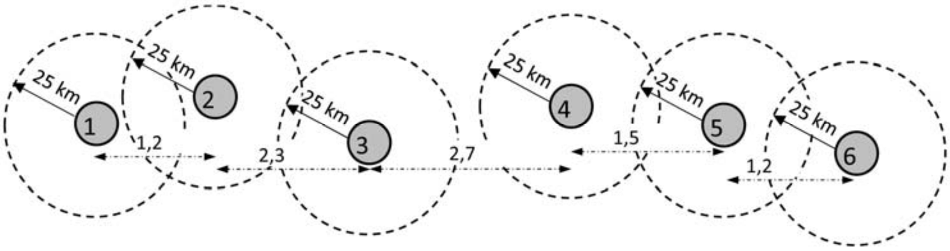


Fig. 3. The example of a real MPSS's configuration for some terrain and secure conditions (the sketch is not at scale)

So, for such occasional conditions of systems' utilization there is not just a technical optimization problem (which defends only from specifications of a system), but a procedure one too, especially how to get the best approaches for next processing of ongoing datasets during the time of MPSS's functionating.

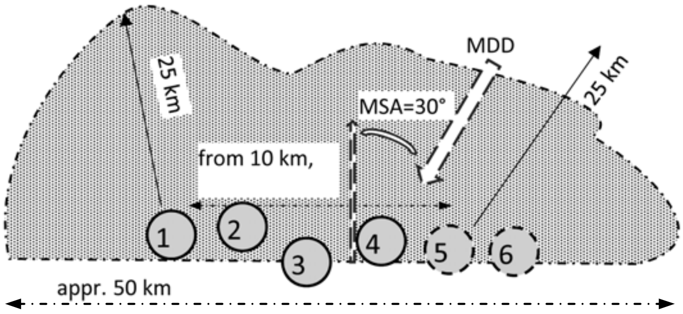


Fig. 4. The variant of the real AoI for s MPSS's (MPSS's sensitivity)

The acoustic location multi-position surveillance system

The stages of data preprocessing and data processing are presented on the example of an acoustic location MPSS.

The principles of acoustic MPSS are well-known: due to automatized detection and classification procedures, sensitive synchronous sensors and wireless communications the determination of the sound source from the muzzle wave Times of Arrival is a simple task for such kind of MPSS [8]. But the problems of the sound source location accuracy and even the recognition in typical circumstances when the various waves emitted by and during a shot (from many sound sources) are still actual. The reasons have the nature character — the initial projectile characteristics (the whole variety of its aerodynamic and ballistic coefficients), the range (Fig. 5), the atmosphere (with atmospheric wind (Fig. 6) and

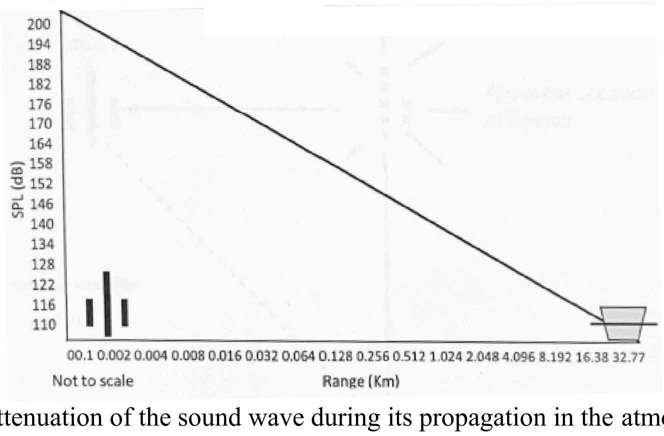


Fig. 5. The attenuation of the sound wave during its propagation in the atmosphere [11]

sound speed gradients), the ground, possible obstacles (woods, buildings, hills…, (Fig. 7)), refraction or air absorption, wave alterations, multipath arrival of the ballistic shock wave and so on. So, the outcome that the localization performance is affected, sometimes critically [9], is firm. Even more, the practice with highly intensive shot conditions that took place in Ukraine since 2022-24-02 [10], approved this statement.

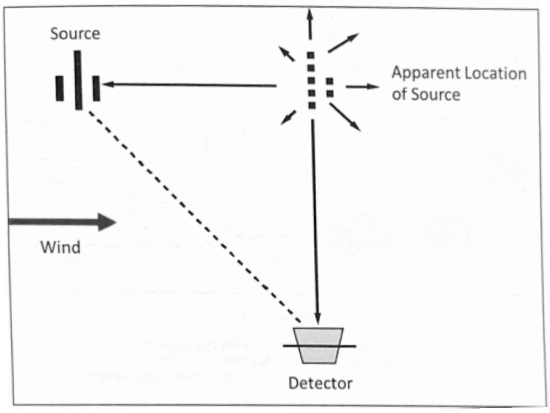


Fig. 6. The wind influence on the sound wave and source's localization [11]

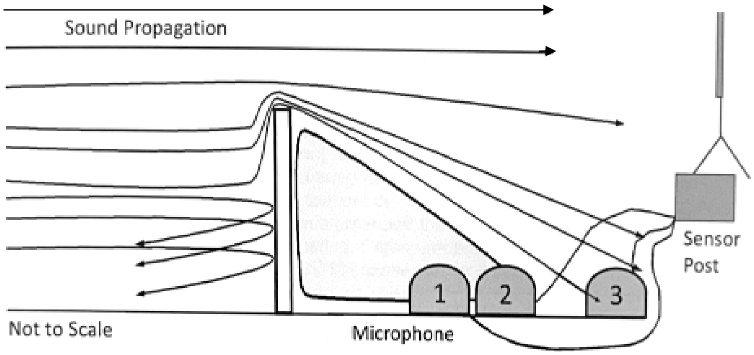


Fig. 7. The probable role of obstacles on the sound wave path in poor operation of a MPSS' sensor [11]

Therefore, many modern researchers are dedicated to improving the accuracy of acoustic MPSS in sound source localization. There are two main directions of the efforts: 1) to improve the established approaches (due to technical and different tools' progress, and processing method with some more efficiency [8; 9; 12; 13]); 2) to search new approaches for problem solving. The example of the second direction is an application of artificial intelligence — convolutional recurrent neural networks in [14] or other neural networks on the proposed software-mathematical models [15], depending on the shape of the location of the sensors (MPSS's configuration), the distance between SP, their number, the parameters of the neural network (the number of hidden layers and neurons), and the volume of the dataset for training. The authors proclaimed that their results for the neural network training algorithm ensure the average value of the absolute error in determining the grid coordinate are not exceed about 1 m and maximum absolute error value are not exceed 16 m for the Y grid coordinate (it corresponds the determination in depth) and 4.5 m for the X grid coordinate (it corresponds the determination in front) for the range 1800 m between sensors and a source of acoustic signals. Even if it is a fact for testing conditions (optimal terrain specification and for an ideal configuration (Fig. 1) it is not useful for real circumstances, because the practical range between SP and a sound source is in 5…15 times much more, that means the average or maximum absolute error values are increasing properly — up to 50…300 m.

To approve the mentioned statement the field data are presented below.

Some field data from the acoustic MPSS and their explanation

The type of acoustic MPSS for the gathering data in field conditions is HALO [11]. According to the specifications of the HALO system the average value of the absolute error should be 100 m on the range up to 100 m and 0.7% of the range when the distance to the sound source exceeds 15 km.

The configuration for the HALO was occasional (Fig. 3) and included or 4, or 5, or 6 sensors with distance between them from 1.5 km till 4 km.

The field results for initial utilization of HALO are shown in the Table 1.

Table 1. The initial data about HALO's accuracy

Range between MPSS and sound source	**Number of sensors with the base line distance**		
	5 SPs for 13.8 km *or* 6 SPs for 16.5 km		4 SPs for 11.2 km
	MSA (*see Fig. 4*)		
	0…±30 °	±30…±60 °	0…±30 °
	The average value of the absolute error		
7…10 km	200…300 m	500…700 m	500…800 m
10…15 km	400…500 m	1000 m	1000…1500 m
15…20 km	600…800 m	1500…2000 m	-
20…30 km	1000 m	-	-

A note: 1 — The time period of observation is a month (since 2023-05-04 till 2023-08-05).

To estimate the value of the error it was possible to use the radar system for the same sound sources. The type of the radar is AN/TPQ-36 with accuracy up to 50 m [16].

Table 2. The comparison data between Radar's and HALO's target grid coordinates

Nr.	**Detection time**		**Location difference, m**	**Range** (between SPs of MPSS and sound source)**, m**	
	HALO	Radar			
1	23:24	23:30	818	22240	26920
2	23:25	23:30	877	- // -	- // -
3	10:15	10:20	391	15310	18830
4	10:18	10:20	151	- // -	- // -
5	10:42	10:55	108	15480	19020
6	10:46	10:55	46	- // -	- // -
7	10:38	10:30	98	13320	16720
8	10:39	10:30	198	- // -	- // -
9	16:21	16:20	513	21790	26400
10	08:36	08:38	145	15480	18990
11	08:38	08:38	419	- // -	- // -
12	08:19	08:20	153	15390	18940
13	08:21	08:20	226	- // -	- // -
14	08:23	08:20	446	- // -	- // -

It is obviously that the statistical data for reliable conclusions are too little. But the main value of the data is their real (utilization) nature, not experimental.

It should be noted that the influence of meteorological data (which is required for HALO) was not considered. The average data are presented in the Table 3.

Table 3. The average data of HALO's accuracy during the field utilization

Range between SP and sound source	Manual's meaning of HALO's error	The deviation diapason of sound source's coordinates from actual ones
15…20 km	105…140 m	up to 100 m
20…30 km	140…210 m	500…900 m

A note: 1 — The MPSS consists of six SPs, the MPSS's base line is 16.5 km, the MSA is 0…±30º.

So, the average error values may correspond to manual's ones (according to HALO's specifications) on the ranges up to 20 km. But it is not enough for direct application the surveillance data on next stages of decision-making. So, it is necessary to find approaches how to decrease average and maximum absolute error values.

The input conditions and restrictions

The objective of monitoring by means of MPSS is to determine the location of the targets after at least two systems' sensors produced information about detection of the target.

The MPSS consists of 6 sensors [10].

The fact of generating some kind of signal that was received/detected by a sensor(s) will be called an event.

The detected signal is the information about event transformed in some digital form including some specific features about the event, like time and potential coordinates.

The digital event set (DES) is the ordered combination of numbers that is generated by a sensor detecting the signal. Normally the DES includes time of detection, coordinates of a sensor that detects a signal and coordinates of an event, derived from some signal and information processing.

The proposed dataset is the collection of DES collected during some period of MPSS's operating. Several dataset sources can be used, so the corresponding indication of those sources is included where needed.

The size of dataset is more than 17 000 rows. The example of the raw dataset is shown on Fig. 8 (its description is given in the note under the figure's title). So, the presented digital data for the data preprocessing and EDA were used similar to [17]. Gaining the ability to evaluate the performance of the MPSS depending on the configuration is easily (to a certain degree) doable.

Time of occurrence of the event isn't taken into account for the statistical analysis.

The common operational picture (COP) is a presentation of all detected events on some grid system.

SOLVING THE PROBLEM OF INEFFICIENCY OF MULTI-POSITION SYSTEM IN UNPREDICTABLE AND VARIABLE ENVIRONMENT

Experiment Design/Data Collection

To represent results of dataset processing including corresponding diagrams and graphic elements in the best form some abbreviations and acronyms for the terms and processes taking place in our research are proposed (Table 4).

Table 4. A physical essence of some processes in MPSS with designations and symbols

N	The terms and their designation or symbolization		
	Term or characteristics	Acronym	Symbol
1	Configuration	Conf.	$\langle Conf \rangle^j$
2	Number of sensors in a configuration	–	K
3	Sensor Post from a configuration with a sequence number[1] k	SP	SP_k
4	Configuration Duration[2]	CD	T
5	Configuration Sencitivity Terrain[3]	CST	(X,Y)
6	Number of Events being Detected[4]	NED	N
7	Event sequence number	i	$\dots_i$
8	Total Events Space Distribution	TESD	$\{W\}_i$
9	Event Space-Gradient Map[5]	ESGM	$\{\widetilde{W}\}_K$
10	Locating Posts' Number Portion[6]	LPNP	$P_{\hat{n}}$
11	Single Post Operating	SOP	P_k

Notes: 1 — It is generated in MPSS automatically; 2 — Time period of MPSS's operating with some configuration; 3 — Some terrain (with defined size) that is being achievable for MPSS to detect events; 4 — Using upper and lower indexes it is differed a NED for one or another configuration and/or CDs (f.e., per a day, per a week, …); 5 — It shows the terrain (as a gradient surface) in which events were detected by all SPs; 6 — The ratio of number of SPs that detected each event to all SPs from a configuration

The methodology aspects for analysis of MPPS

Specialized geoinformatics system (GIS) software is usually integrated into MPSS to display the current event situation [18]. Usually, such GIS is a 3D model of terrain with a set of coordinate systems. In the research it was used a relative simulated Cartesian coordinate system (CCS) that "covers" a CST and displays the configuration in the center of it. So, all events detected by SPs are reproduced on this simulated CCS.

The ontology of a configuration is depicted as

$$\langle Conf \rangle^j \rhd (K, \{\lambda\phi\}_k)^j , \qquad (1)$$

where j is a relative sequence number for possible configurations (there were 6 ones); K is the number of sensors in a configuration; λ & ϕ are the coordinates of SP (a longitude and a latitude for SP_k). Sometimes the UTM-like coordinates are used instead of latitude-longitude, but the conversion between those is a simple computational task:

$$\{\lambda\phi\}_{\ldots} \to \{X\,Y\}_{\ldots} \ . \tag{2}$$

ML system has a typical design for such systems [9].

The ontology for configuration quality estimation

A collection of several statistical characteristics that are used for demonstration and estimation of how a specific configuration operates in a CST is called the configuration quality (CQ) within the context of the paper.

TESD shows the density of detected events:

$$\{W\}_i = \sum_{i}^{\hat{N}_{total}} \{X,Y,t\}_i \,, \tag{3}$$

where $\hat{N}_{total}$ is a total NED for the *j*-configuration.

ESGM shows the terrain area where the events were detected by all SPs:

$$\{\widetilde{W}\}_K = \bigcap_{k=1}^{K} \{W\}_{i/k} \,, \tag{4}$$

where $\{W\}_{i/k}$ is an event distribution detected by SP_k.

Apparently, each event may be detected by a single SP or by a particular combination of SPs. Consequently, LPNP is defined as:

$$P_{\hat{n}} = N_{\hat{n}} \,/\, \hat{N}_{total} \,, \tag{5}$$

where $1 < \hat{n} \le K$, meaning that $N_{\hat{n}}$ is a sum of NED for the cases detected by a combination of $\hat{n}$ SPs (neglecting the actual composition of SPs in the combination, only the number of SPs is considered).

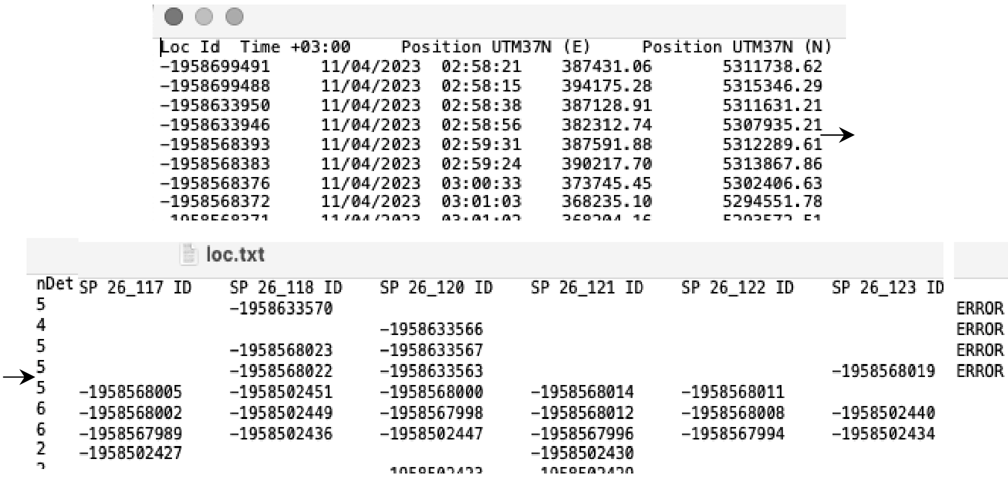
SOP shows how frequently each single SP detected events registered in the dataset:

$$P_k = N_k \,/\, \hat{N}_{total} \,, \quad k = (1\ldots K) \,. \tag{6}$$

Configuration quality CQ presentation

So, there were 6 configurations with different parameters according to (1). Each configuration had a NED that is enough for ML (see depiction for figures). To analyze CQs it was proposed to calculate and present five graph materials for each configuration.

TESD presents the distribution of events that were detected in MPSS during time period corresponding to configuration duration *T*. Each point for presentation it was taken from geographic coordinates of corresponding row of dataset (Fig. 8) according to (3). The geographic coordinates were transformed into grid one according to (2). The grid system is conditional and it has no connection with any known grid systems such as MGRS. It was got just for local terrain. The central point for this grid is approximately in the geometric center of MPPS's base that includes all sensors. As common the form for MPSS's base is similar to line. The limits for terrain area are not far than the biggest distance (from central point to event's location) projected on grids. In the presented case there is a 50-km area from the geometric center (in each of four grid directions). Due to terrain scale restrictions, it was used a gradient scale to present the level of concentration detected events in limited location areas. For example, gradient scale is from 0 to 80 on a Figs. 9, 11, 12, 13, 17, 18.



Loc Id	Time +03:00		Position UTM37N (E)	Position UTM37N (N)
-1958699491	11/04/2023	02:58:21	387431.06	5311738.62
-1958699488	11/04/2023	02:58:15	394175.28	5315346.29
-1958633950	11/04/2023	02:58:38	387128.91	5311631.21
-1958633946	11/04/2023	02:58:56	382312.74	5307935.21
-1958568393	11/04/2023	02:59:31	387591.88	5312289.61
-1958568383	11/04/2023	02:59:24	390217.70	5313867.86
-1958568376	11/04/2023	03:00:33	373745.45	5302406.63
-1958568372	11/04/2023	03:01:03	368235.10	5294551.78

loc.txt

nDet	SP 26_117 ID	SP 26_118 ID	SP 26_120 ID	SP 26_121 ID	SP 26_122 ID	SP 26_123 ID	
5		-1958633570					ERROR
4			-1958633566				ERROR
5		-1958568023	-1958633567				ERROR
5		-1958568022	-1958633563			-1958568019	ERROR
5	-1958568005	-1958502451	-1958568000	-1958568014	-1958568011		
6	-1958568002	-1958502449	-1958567998	-1958568012	-1958568008	-1958502440	
6	-1958567989	-1958502436	-1958502447	-1958567996	-1958567994	-1958502434	
2	-1958502427			-1958502430			

Fig. 8. The example[1] of real data from a MPSS

A note: 1 — MPSS generates automatically unique identification numbers for each sensor that detects a target and for a whole system when at least two sensors detect the same target (the number of sensors that detect a joint target is ina column that is headed as nDet). The corresponding identification numbers (ID from one of six sensors (they are defined as SP_117, SP_118, etc.) and Loc ID from a MPSS are presented on the example — 1958699491, 1958633570, etc.). The time detection for a target and its coordinates — geographic longitude and latitude — are also presented in the proper columns

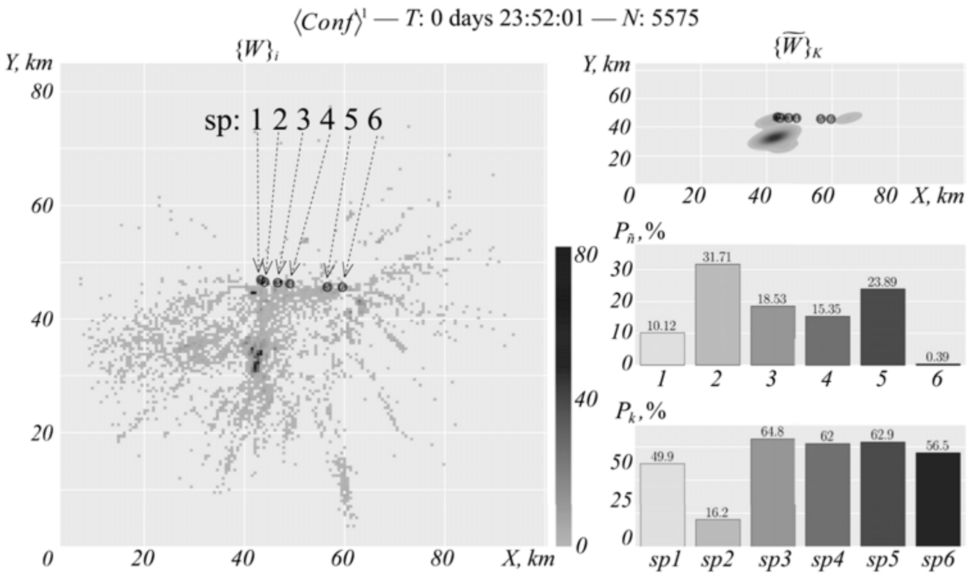


Fig. 9. The Total Events Space Distribution $\{W\}_i$ (half-left), Event Space-Gradient Map $\{\widetilde{W}\}_K$ (top-right), Locating Posts' Number Partion $P_{\hat{n}}$ (middle-right) and Single Post Operating P_k (bottom-right) for Configuration Nr. 1 of MPSS ($T \approx d$, NED (corresponds to the size of dataset) $N = 5575$

The next graph of CQs (top-right) shows the gradient distribution of detected events that were detected by all 6 sensors of MPSS simultaneously (or with understandable time delay) according to (4). The graph allows to estimate both some aspects of MPSS's configuration and terrain peculiarities. In first case the operator of MPSS may define ineffective sensors in case when the following result is happened: the event is localized in the whole-area but there is no detected information from one (or more) sensors of 6. In second case the operator could analyze how the terrain influenced on MPSS's possibilities and what variants of changing the configuration would be useful for better detection.

The third illustration of CQs (middle-right) is a diagram showing what is a portion of numbers of sensors in event detection according to (5). As it was mentioned in the Fig. 8's note, there are unique identification numbers in the MPSS — location ones and numbers from each of 6 sensors. The quantity of unique identification numbers from all sensors corresponds to number of events. Some of these events "becomes" targets — it happens when the event has two or more identification numbers from sensors that makes possible event's location with simultaneous generating the location identification number. So, the diagram shows the distribution of identification numbers depending on how many sensors define events one-by-one. It is clear that a portion that is corresponded to a single sensor high-probably identifies the occasional (low, bad, poor, week, strange) signal. It is impossible to locate an event due to "detection" from a single sensor. So, such information could inform the operator that configuration has some week points and it will be good to reduce the portion of identification numbers from one any sensor. The "ID-portions" for two or more sensors are normal for MPSS because of variety of signals on sensors' inputs — the range, terrain features, source of the signal, etc. make probable possibilities for the sensors to detect them. It is obviously that what a concrete combination for two (for three and partly for four) sensors for one-by-one events is could guess the operator some other configuration week points. But the decision needs more high computation for such analysis — the distribution of identification numbers is multiplied (5!+4!+3!=150), so it wasn't executed for this paper.

The fourth diagram of CQs (bottom-right) shows what is a portion of numbers of sensors in event detection. In general, the diagram expresses (6).

The fifth graph material of CQs is a normalized contingency (crosstab) table (see Figs. 10, 14, 15, 16, 19, 20) that shows the relative frequency of detections made by a specific *SP* depending on *SP*s' combination.

$\langle Conf \rangle^I$

	SP1	SP2	SP3	SP4	SP5	SP6
1.0	1.11	0.41	1.20	2.21	3.05	2.13
2.0	11.75	3.84	14.04	8.25	12.91	12.61
3.0	10.85	1.51	11.91	14.74	8.86	7.71
4.0	10.24	1.72	13.36	12.52	13.83	9.74
5.0	15.57	8.34	23.87	23.89	23.89	23.89
6.0	0.39	0.39	0.39	0.39	0.39	0.39

Fig. 10. The crosstab of SP_k -detection for Configuration Nr. 1

Let's show how to make the qualitive analysis of the illustrated data for this configuration of MPSS (it is the Conf. Nr 1 above).

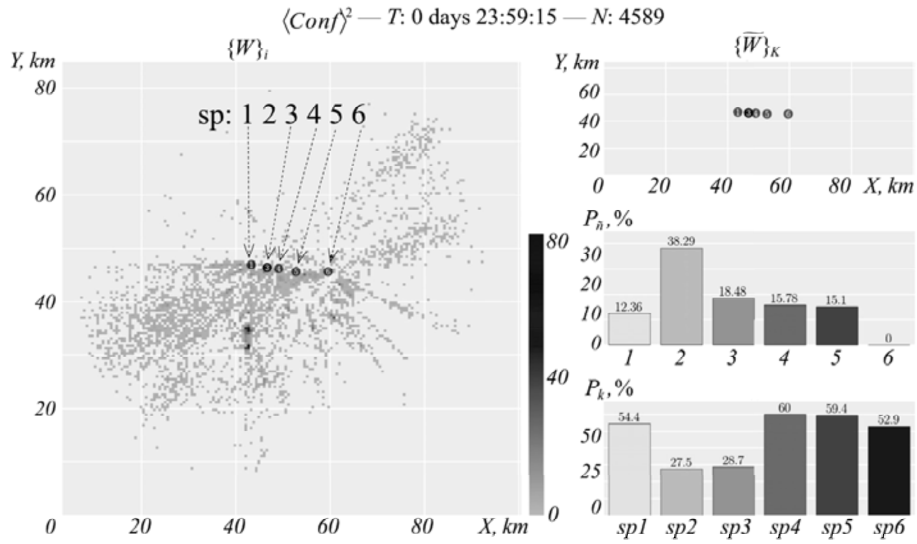


Fig. 11. CQs for $\langle Conf\rangle^2$ ($T = d$, dataset size $N = 4589$): $\{W\}_i$, $\{\widetilde{W}\}_K$, $P_{\hat{n}}$, P_k

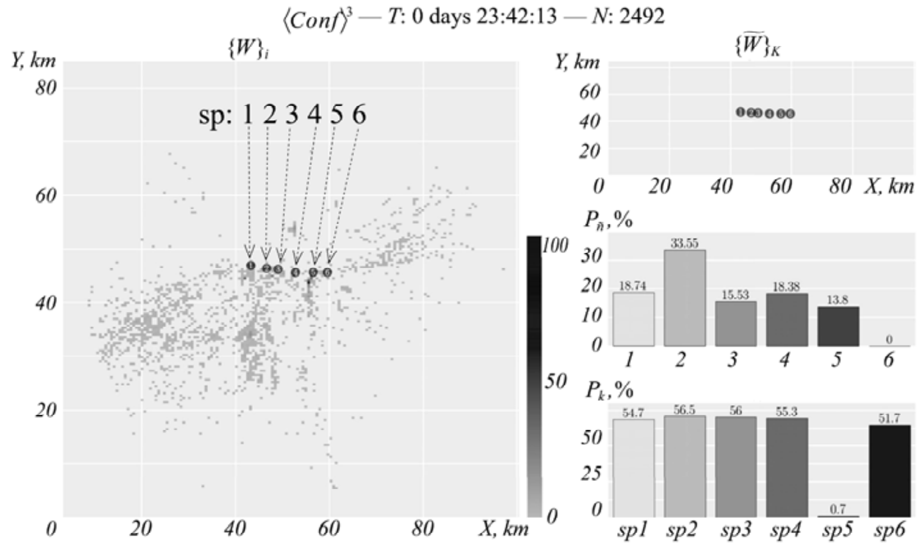


Fig. 12. CQs for $\langle Conf\rangle^3$ ($T \approx d$, dataset size $N = 2492$): $\{W\}_i$, $\{\widetilde{W}\}_K$, $P_{\hat{n}}$, P_k

Each point on the graph for TESD $\{W\}_i$ shows the sound event that took place during the observation time. It doesn't differ what is a source of the detected sound event — gun fire moment or any kind of explosion caused by a shell, or by a missile, or by a mine, even engine switch-on is possible to detect (it is clear because the SP has a stable determined sensitivity (Fig. 5)). For such circumstances the COP depends on terrain features (relief forms and artificial and natural coverings effect on sound wave propagation). So, making the COP's observation during the determined time period it is possible to get some qualitive analysis — what concrete terrain areas have much more "signals" (they correspond to sound events that were detected in MPSS) and what other terrain areas are "problematic" (there are a smaller number of "signals" then it is expected for typical situation of the initial preposition that there are continuous uniform distributions for signal events — in fact it is necessary to combine the intelligence data with other sources to approve the preposition as it is shown in [17] but for this research it doesn't matter). For the "ideal" efficiency it is demanded to have the COP with no blank terrain areas for the whole attention sector (it corresponds roughly to surveillance area).

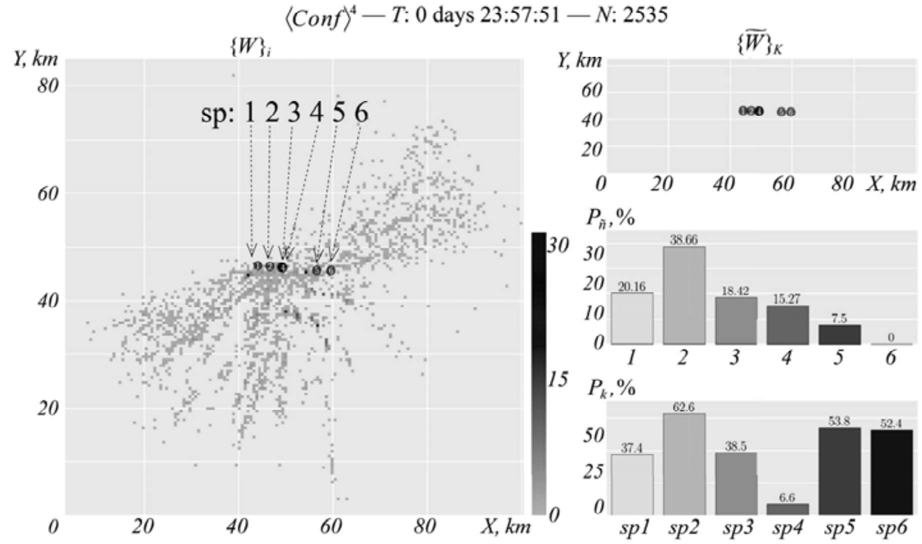


Fig. 13. CQs for $\langle Conf \rangle^4$ ($T = d$, dataset size $N = 2535$): $\{W\}_i$, $\{\widetilde{W}\}_K$, $P_{\hat{n}}$, P_k

So, for the Fig. 9 it is possible to define some problematic areas (and the directions from the MPSS' configuration center) — they are in the south-east part of the COP (the top-right figure for the ESGM $\{\widetilde{W}\}_K$ shows the general depiction for the COP during the time period observation).

Using the diagram for the SOP P_k (see bottom-right) helps to see the "problematic" SP (SPs). Here for the Conf. Nr 1 the "problematic" SP is the "second" — SP2 with $P_k = 0{,}16$ (16.2%-participation in MPSS' total detection although other SPs give 50% or more results). So, the qualitive analysis for this case shows that it is necessary to reset the SP2 on the terrain — to change its location.

Using the diagram for the LPNP $P_{\hat{n}}$ (see middle-right) allows to identify another "problem" — how often single SP operates. The such qualitive analysis is a base for next statistical and/or technical analysis because all SPs are identical ones and sound wave for typical conditions (for all SPs of MPSS they are similar at least) should be detected by two or more SPs (it depends on distance from the source and angle of the direction of sound wave propagation). So, the qualitive analysis for this case allows operator to define some "blind" directions or other possible reasons that cause less more efficiency for MPSS. The outcome of such analysis should be adjusting of a "problematic" SP (its sensitivity or other organizing measures to stop the detection (to blank) of the unwilling or other parasitic sound wave signals). For this task the normalized contingency table (Fig. 10) should be useful. Here it is presented that SP4 (with 2.2%), SP5 (with 3.1%) and SP6 (with 2.1%) have higher portion of only theirs SOP (without co-detection). Naturally that the qualitive and statistical analysis should be made for all combinations of different co-detections that took place in the MPSS — such wide analysis of crosstab's data from Fig. 3 will allow to define weak points of the analyzed configuration and to search the ways of MPSS's adjusting or new variant of the configuration. The last approach is presented in the paper furthermore — there are five more variants of MPSS's configuration with CQ's calculated data for each configuration as presented on the Fig. 9 and 10.

Using the crosstab allows to find the SPs with the best "collaborative" features (optimal co-detection). It means that for the detecting of the sound wave and next determination of the sound source's coordinates it is demanded to have the detection from two or more sensors. So, what SPs have the high level of co-detection for two sensors or for three sensors in different combinations it will give the optimal configuration of the MPSS. It is a classic optimization problem for non-optimal terrain accessibility.

So, following CQs are presented for other MPSS's configurations — the figures are grouped correspondingly (see Fig. 11 & Fig. 18 for Conf. Nr. 2, Fig. 12 & Fig. 15 for Conf. Nr. 3, Fig. 13 & Fig. 16 for Conf. Nr. 4, Fig. 17 & Fig. 19 for Conf. Nr. 5 and Fig. 18 & Fig. 20 for Conf. Nr. 6).

$\langle Conf \rangle^2$

	SP1	SP2	SP3	SP4	SP5	SP6
1.0	0.96	0.33	0.31	0.94	3.38	6.45
2.0	15.52	7.52	7.50	14.51	17.67	13.86
3.0	10.66	5.88	5.97	14.80	10.39	7.74
4.0	12.20	7.21	6.41	14.62	12.88	9.78
5.0	15.10	6.54	8.56	15.10	15.10	15.10

Fig. 14. The crosstab of SP_k-detection for $Conf^2$

$\langle Conf \rangle^3$

	SP1	SP2	SP3	SP4	SP5	SP6
1.0	0.40	0.36	0.28	0.88	0.00	16.81
2.0	15.33	15.89	11.56	14.41	0.20	9.71
3.0	9.11	9.71	13.20	8.63	0.08	5.86
4.0	16.05	16.77	17.13	17.62	0.12	5.82
5.0	13.80	13.80	13.80	13.80	0.28	13.52

Fig. 15. The crosstab of SP_k-detection for $Conf^3$

$\langle Conf \rangle^4$

	SP1	SP2	SP3	SP4	SP5	SP6
1.0	0.42	5.01	3.16	1.89	4.42	4.26
2.0	11.32	21.78	8.68	2.64	15.86	17.04
3.0	7.46	13.93	8.72	1.03	12.70	11.44
4.0	9.70	14.36	10.77	0.71	13.37	12.15
5.0	7.50	7.50	7.14	0.36	7.50	7.50

Fig. 16. The crosstab of SP_k-detection for $Conf^4$

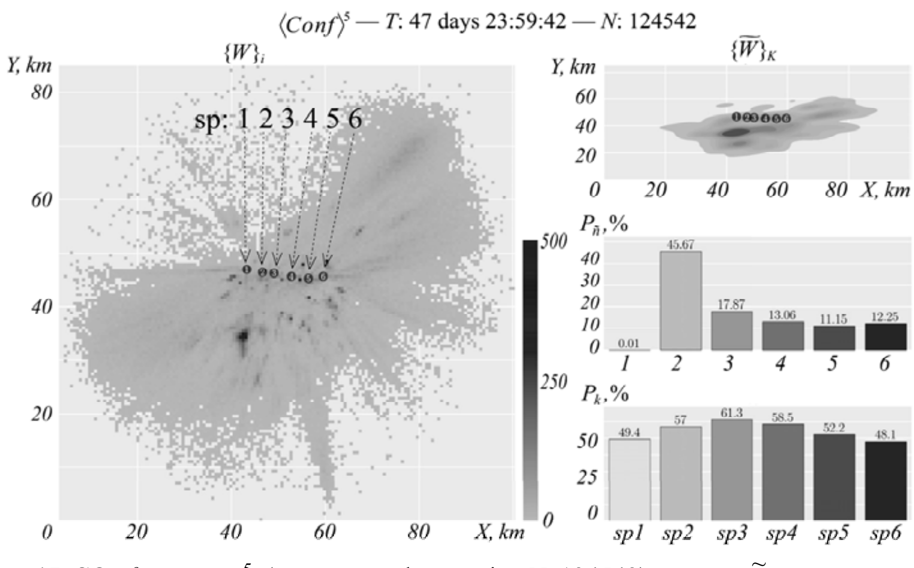


Fig. 17. CQs *for* $\langle Conf \rangle^5$ ($T = 48 \times d$, dataset size N=124542): $\{W\}_i$, $\{\widetilde{W}\}_K$, $P_{\hat{n}}$, P_k

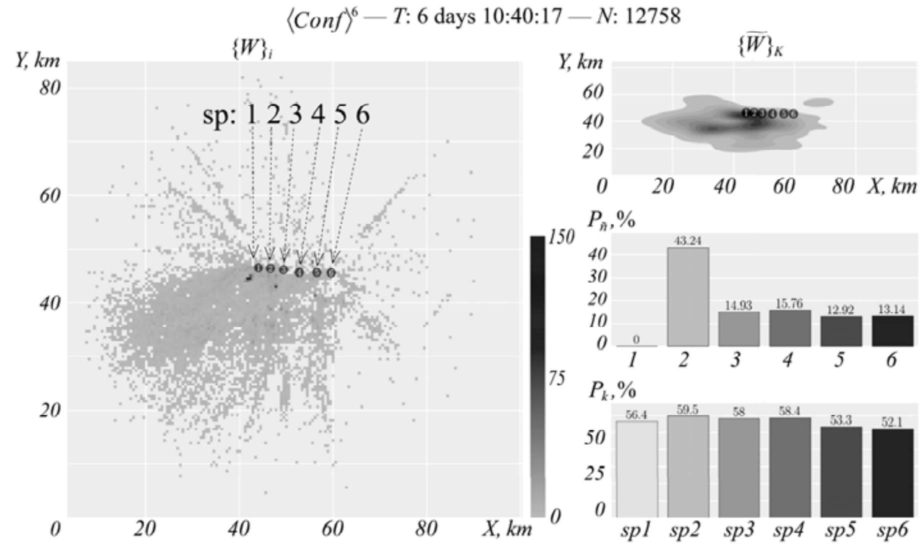


Fig. 18. CQs *for* $\langle Conf \rangle^6$ ($T \approx 6 \times d$, dataset size *N*=4589): $\{W\}_i$, $\{\widetilde{W}\}_K$, $P_{\hat{n}}$, P_k

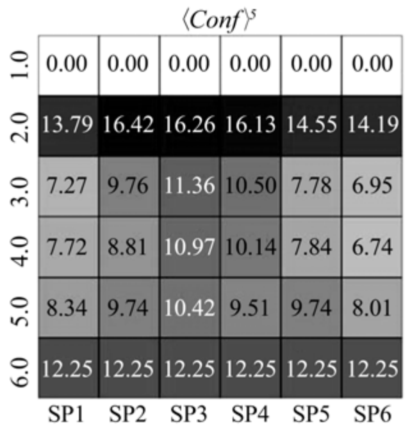


Fig. 19. The crosstab of SP_k-detection for $\langle Conf \rangle^5$

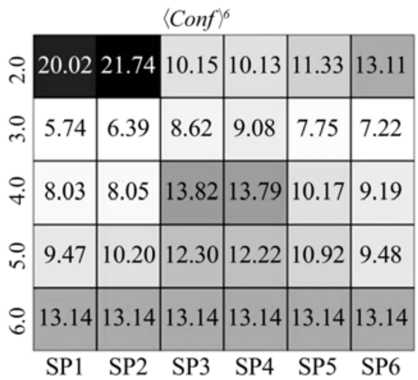


Fig. 20. The crosstab of SP_k-detection for $\langle Conf \rangle^6$

Having some field configurations (it means they were actual on the terrain) itis possible using some qualitive and statistical analysis of the detection efficiency depending on MPSS's configuration and each or some SP(s) operation to find the best (the optimal for real terrain or other circumstances) configuration for the MPSS. The transforming of the configuration means that some SP(s) are being reset on the terrain (on a new geographic location of the position). Another way of increasing the MPSS efficiency is just the adjusting some features of 'problematic' SP (sensitivity or blank directions (sectors) establishing).

The mode for MPSS's transiting to achieve better detection possibilities

The obtained statistics allows to choose the configuration for MPSS for a particular terrain. For instance, using the computations for (5) and (6) the 'weak' points for each configuration — ineffective SP (SPs) — are obtained. The results allowed to build a priorities scheme (an ontology) to determine where the configuration should be moved towards to — see Table 5.

Table 5. CQs' parameters for best configuration

$\langle Conf\rangle^{j}$	LPNP				SOP min
	for $\hat{n}=2$	for $\hat{n}=3$	for $\hat{n}=1$	for $\hat{n}=6$	
$\langle Conf\rangle^{1}$	31.71	18.53	10.12	0.39	SP2
$\langle Conf\rangle^{2}$	38.29	18.48	12.36	0	SP2, SP3
$\langle Conf\rangle^{3}$	31.85	18.42	18.74	0	SP5
$\langle Conf\rangle^{4}$	38.66	15.53	20.16	12.25	SP4
$\langle Conf\rangle^{5}$	45.67	17.87	0	0	-
$\langle Conf\rangle^{6}$	43.24	14.93	0	13.14	-
Prioritize	↑	↑	min	max	none

The optimal configuration should be one with more portion of two and/or three SPs, with "maximum LPNP" and absent zero or near-zero SOP.

For presented data the optimal configurations were $\langle Conf\rangle^{5}$ and $\langle Conf\rangle^{6}$ — approximately the efficiency exceeds on 10…15% (it corresponds to valueless part of single post operating).

CONCLUSIONS

In the research the variant of additional option in multi-position surveillance system's operating using datasets that are generated in sensors of the system is showed.

One of the key characteristics is a system's configuration which is possible to transit to ensure better efficiency of detection by means of system's sensors. Both the methodology and the ontology for qualitive estimation of different system's configurations are proposed in the paper. The corresponding results are presented using graphic distribution of detected events and diagram for efficiency of system's elements including 6 sensors. The efficiency of MPSS exceeds on 10…15% due to defining the weakest point of multi-position surveillance system and its following transition of system's configuration.

Although the representations with event distributions and SPs' frequencies allow to find the best configuration for MPSS operating, the possibilities of the results are wider. Next step of statistical analysis can be held with respect to the time durations, like estimating average event distributions depending per period, building periodograms and some event dispersions. The ontology and methodology also will be explored in the next researches. In general, the gained results would be useful for system engineering when it's necessary to design both concrete system and system-of-systems including multi-position surveillance system, communication system, GIS, machine learning or deep learning system, etc.

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Received 02.05.2024

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ОЦІНЮВАННЯ ЕФЕКТИВНОСТІ БАГАТОПОЗИЦІЙНОЇ СИСТЕМИ СПОСТЕРЕЖЕННЯ НА ОСНОВІ ДОДАТКОВОГО ОБРОБЛЕННЯ ДАНИХ ВІД СЕНСОРІВ ЗІ ЗМІНЮВАНИМ МІСЦЕПОЛОЖЕННЯМ / В.Ю. Тимчук, О.О. Медяков, О.О. Попов, Т.В. Триснюк, С.А. Цибуля

Анотація. Ефективність багатопозиційної системи залежить від її структури, а саме від кількості елементів (сенсорів) у складі системи та від місцеположення самих сенсорів, які визначають конфігурацію системи, а також від того, як на роботу системи впливають середовище і рельєф місцевості. Розглянуто оброблення даних у багатопозиційній системі спостереження як додаткової операції шляхом збирання та обчислювальних маніпуляцій із великими даними (набором датасетів) з елементів системи. Значний обсяг цифрових даних, що циркулюють у багатопозиційній системі (отримуються від сенсорів системи), уможливлює використання статистичних методів оброблення даних. Запропоновано онтологію для оцінювання якості багатопозиційної системи залежно від її конфігурацій. Результати розподілів виявлених подій подано у графічних формах, що дало змогу виконати статистичну оцінку розподілених даних. Зроблено висновки про спосіб поліпшувати ефективність багатопозиційної системи в непередбачуваному змінному середовищі завдяки зміні конфігурації системи, за якої забезпечують кращі показники якості виявлення.

Ключові слова: оброблення даних, спостереження, виявлення, багатопозиційна система, система систем, ефективність.