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FEATURES OF THE COEFFICIENT OF VARIATION OF PARAMETERS OF THE GAS ENVIRONMENT IN FIRE IN THE PREMISES

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The object of the study is the selective coefficient of variation of dangerous parameters of the gas environment during the ignition of materials. The measure of the sample coefficient of variation of an arbitrary hazardous parameter of the gas environment observed at an arbitrary time interval is substantiated. The representativeness error of the measure of the sampling coefficient of variation, which depends on the value of the measure and the sample size, was determined. The measure allows you to numerically determine its value for an arbitrary observation interval. The difference in the measure at the intervals corresponding to the reliable absence and occurrence of ignition allows to detect the occurrence of ignition of the material. According to the results of laboratory studies, the measures of the sample coefficient of variation for carbon monoxide concentration, smoke density, and temperature of the gas medium in the laboratory chamber at intervals of absence and appearance of ignition of alcohol, paper, wood, and textiles were determined. It was established that the dangerous parameters of the gas environment at the intervals of absence and presence of ignition are characterized by different values of the increase in the measure of the sample coefficient of variation. For example, it is determined that the ignition of alcohol causes the maximum increase in the measure for carbon monoxide concentration from 0.135 to 0.441, for smoke density from 0.629 to 0.805, and for temperature from 0.001 to 0.115. When paper catches fire, the measure for carbon monoxide concentration and temperature increases from 0.0026 to 0.140 and from 0.0019 to 0.05, respectively. When burning wood, the measure for carbon monoxide concentration and temperature increases from 0.0072 to 0.177 and from 0.0067 to 0.016, respectively. The obtained results, provided that the hazardous parameters of the gas environment in the premises are measured and the sample coefficient of variation is calculated in practice, make it possible to use them in the creation of early fire detection systems

Keywords: ignition of material, gas environment, dangerous parameters, measure of sample coefficient of variation

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1. Introduction

The issue of human survival in the surrounding world has always been paramount and is directly related to security issues. The development of humankind has changed the priorities of factors and caused the predominance of man-made threats over natural ones. At the same time, threats of the first type have become complex, affecting not only a person directly but also disrupting the process of his/her life. In peacetime, the main sources of such threats should primarily be considered critical infrastructure facilities. These include objects that are key to the state's economy. The most dangerous of such facilities are energy and oil and gas facilities [1]. The widespread introduction of various digital technologies has led to the emergence of a new dangerous influence on humans from objects in the information domain [2]. This is explained by the fact that modern security systems involve their integration into a wider telecommunications system. Interference with such a system may partially disrupt its operation or completely disable it. At the same time, the highest intensity of dangerous events is associated with fires (F) [3]. Such events pose both a serious threat to human life and cause partial or complete destruction of objects for various purposes [4]. Indirect factors of fire fighting, accompanying the processes of localization and elimination of fires, also negatively affect the environment. In this case, not only the atmospheric air [5] is exposed to pollution from the operation of equipment but also soils and water sources due to the ingress of fire extinguishing agents into them. World statistics show that most of the fires occur at residential and industrial facilities [6]. At the same time, damage in residential buildings is 55 %, and the greatest material damage (45 %) occurs at production facilities. The maximum number of fatalities occurs in residential buildings, and the most common of these are indoor fires (IF). It is known that any P is preceded by combustion (Z). This means that it is possible to counteract the occurrence of fire based on preventive measures, prediction of fire, and detection of combustion (FB) [7]. However, forecasting and preventive measures are aimed at reducing the number of P in the long term [8]. Timely air pollution makes it possible to prevent its development into an uncontrolled problem. Therefore, the problem of air pollution in premises at the stage of their occurrence remains relevant.

2. Literature review and problem statement

The difficulty of solving the problem of air pollution under consideration is determined by the complex and individual physical mechanisms of interaction of the fire source with the dangerous parameters (DP) of the gaseous environment (GE) of the premises. Under real conditions, these mechanisms turn out to be quite complex. Preventive measures and forecasting technologies [9] are based on simplified deterministic models of the dynamics of hazardous parameters (DHP) of GE, depending on 12 or more parameters that are not universal and are usually unknown in advance. This does not allow the use of these technologies to solve the problem under consideration. VS technologies based on group processing of GE DP measurements using the same and different types of sensors are given in [10, 11]. However, the scope of application of these technologies is limited only to the case of Gaussian statistics of DP GE observed against the background of additive noise. The statistical features of real GE OPs in the absence and presence of GE, which are important for EO, are not studied. In this case, an important indicator of descriptive statistics of DP of GE can be the coefficient of variation of DP, which characterizes the degree of current deviations from the average value of DP. Experimental combustion of wood under the influence of an external source of thermal radiation with parameters of 30, 40, and 50 kW/m^2 is studied in [12]. A linear dependence of the average heat release rate on the intensity of thermal radiation has been established. The presence of two peaks in the heat release rate is noted in the interval from the beginning to the end of the radiation, as well as two characteristic peaks of smoke, one before the moment of ignition, and the other after charring of the wood. However, sample distributions, dispersion, coefficients of variation, and corresponding moments of the experimental dynamics of temperature and smoke density during wood combustion are not studied. The influence of wood combustion intensity on the GE DHP in the form of temperature is studied in [13]. In this case, research is limited to studying the influence of the average intensity of combustion of the material on the average dynamics of the temperature of the GE. Similar studies for organic glass and cypress were carried out in [14]. At the same time, in [12–14] there are no studies of the characteristics of the statistical indicators of the main DP GE at intervals before and during the start of F materials, which represent information important for EO. The results of fire tests taking into account the random factor are considered in [15]. It is noted that in order to increase the reliability of air intake under real conditions, it is advisable to take into account the joint change in CO concentration and GE smoke density. In [16], mutual connections between various GE OPs are studied. However, studies are limited to only assessing correlations that characterize exclusively linear relationships. In this case, characteristics of order higher than the second in the frequency domain, which make it possible to identify nonlinear connections, are not studied. In [17], a modified method of adaptive recurrence diagrams was proposed. However, the method in [17] turns out to be quite difficult to implement. At the same time, simpler technologies based on indicators of descriptive statistics of the dynamics of DP GE for characteristic intervals of the absence and beginning of fire are not considered. The VZ technology based on the features of autocorrelations of the DP GE is considered in [18]. The use of the DP GE structure function for VZ is contained in [19]. The use of the GE DP uncertainty function for EO is studied in [20]. Moreover, in [18–20], the results are limited to consideration of moments not higher than the second order of distributions of the DP. The use of moments higher than the second order or specific variations of DP GE before and after F of materials are not considered. The capabilities of VZ based on the characteristics of mutual correlations of various OPs are studied in [16]. It was found that the cross-correlation of DP is determined from –0.85 to +0.68. At their core, correlations, being moments of the second order of distributions, make it possible to identify the features of only a linear mutual connection. However, moments of the third and fourth order, which make it possible to identify nonlinear relationships, as well as their specific variations, are not studied. Features of the third-order amplitude spectra of DP GE are studied in [21]. It has been established that third-order amplitude spectra allow EO based on the nonlinear relationship between the frequency components in the spectrum. However, the effectiveness of such an EO depends on the energy of the observed DP. Therefore, to eliminate this dependence, a BZ based on bicoherence (BC), invariant to the energy of a specific DP, was proposed [22]. However, in [21, 22], EPs are produced based on a sample bispectrum (BS) estimate, which differs from the classical BS estimate, determined by averaging the sample BS estimate over an ensemble of realizations [23, 24]. A comparison of BC [22–24] was made in [25]. It has been established that BC based on [23, 24] have great potential from the point of view of EO. It should be noted that VZ based on BS and BC [21, 22, 25] turn out to be difficult to implement and are based on estimates of the DP spectra. However, spectrum estimation involves moving from the time domain to the private domain. At the same time, under conditions of nonstationarity and uncertainty of the GE DHP, it is problematic to carry out such a transition correctly. The statistical properties of the distribution of the coefficient of variation are studied in [26]. However, it is assumed that the sample is drawn from a Gaussian distribution. This significantly limits the use of the results in the case of samples from data that have a non-Gaussian distribution. The asymptotic properties of the distribution of the coefficient of variation for random dependent data are considered in [27]. It is shown that in the case of non-identical data distributions, there are limiting distributions for the coefficient of variation, which expand the possibilities of using estimates of their statistical parameters. The use of the coefficient of variation in psychology is given in [28]. The application of the coefficient of variation in hydrology is discussed in [29]. A three-step method for estimating the coefficient of variation is proposed in [30]. However, the proposed method is limited to estimating the inverse coefficient of variation and studying the second type error using the Monte Carlo procedure. Thus, despite the noted wide possibilities of the coefficient of variation, in [26–30] there are no studies of the features of the coefficient of variation of the DHP GE characteristic of the initial stage of CM.

Therefore, there is a need to study the features of easy-to-implement descriptive statistics of sample DHP GE, in the form of a coefficient of variation. In the general case, the coefficient of variation makes it possible to estimate the average deviation of DHP per unit of average dynamics. In this case, the coefficient of variation is dimensionless and allows one to compare the influence of F on different OPs of the GE. In this regard, an unsolved part of the problem under consideration that should be considered is the analysis of characteristics of the coefficient of variation of the DHP GE when F occurs in the premises.

3. The aim and objectives of the study

The purpose of our work is to identify the features of the coefficient of variation of dangerous parameters of the gas environment during the intervals of absence and occurrence of materials ignition. The features of the coefficient of variation of hazardous parameters of the gas environment at time intervals corresponding to the absence and presence of fires of materials are of practical interest from the point of view of early detection of fires and prevention of fire.

To achieve the goal of the work, the following tasks were set:

– to justify the measure of the sample coefficient of variation for an arbitrary dangerous parameter of the gaseous environment observed over an arbitrary fixed time interval;

– to conduct laboratory experiments to identify the features of the measures of variation for dangerous parameters of the gas environment during the intervals of the absence and beginning of a fire.

4. Materials and methods of research

4. 1. Materials of the study

The object of this study was measures of the coefficient of variation of DP GE in a laboratory chamber at specified intervals of the absence and occurrence of F of test materials (TM). The working hypothesis was the difference in the measures of variation in the DP of the GE at the intervals of the absence and occurrence of F of TM. In this case, it was assumed that the nature and properties of the DHP of the GE at 3D in real rooms are identical to the dynamics in the laboratory chamber [31, 32]. Alcohol, paper, wood, and textiles were chosen as TMs. The studied OPs in the chamber were temperature, smoke density, and concentration of CO GE [33]. GE temperature was measured with a TPT-4 sensor (Ukraine) [34], smoke density with an IPD-3.2 sensor (Ukraine) [35], and CO concentration with a Discovery sensor (Switzerland) [36].

4. 2. Research methods

The main method was a selective method for estimating the coefficient of variation of DP of GE based on current measurements of the parameters of the DP of the GE in a laboratory chamber at F of HM. Measurement of DP GE [37] in the chamber was carried out by appropriate sensors, which were located in the ceiling area [38]. Continuous DP measurements were performed discretely in time with an interval of 0.1 s. To study the features of the measure of the sample coefficient of variation of the DHP GE, two characteristic intervals of the same duration were identified. The first interval (T0) corresponded to the significant absence of TM F. The second interval (T1) – reliable TM F. During the study, TM F was produced approximately in the middle of the second characteristic interval. The duration of each interval was determined by 100 discrete measurements. The results of measurements of the DP GE were stored in the computer memory for subsequent processing. The peculiarity of the study was the sequential order of TMs F: the first was to produce alcohol F, the second – paper, the third – wood, and the fourth – textiles. After F each of the materials, natural ventilation of the chamber was performed for 5–7 minutes. Such ventilation made it possible to restore the initial state of the DP GE before each TM F. Measurement processing was based on nonparametric estimation of sample moments of an unknown distribution [39].

5. Results of the study of sample coefficients of variation for hazardous parameters of the gas environment at characteristic intervals

5. 1. Justification of the sample coefficient of variation measure

Let the implementation x of some DP GE be observed on an arbitrary time interval. In this case, the observation result is determined by an independent sample of measurements $(x_1, x_2,..., x_n)$ of a fixed size n. The sampling distribution $w_1(x)$ belongs to the nonparametric family W. In this case, the kth m_k^* order sample moment will be determined by the expression:

$$m_k^* = \sum_{i=1}^{n} x_i^k / n, \text{ where } k = 1,2,.... \quad (1)$$

Following [40], the sample moment (1) converges in probability to the corresponding moment of the distribution. However, sample moments (1) are random, while distribution moments are constant non-random numbers. Along with (1), we will use the central sample moment of the kth order:

$$\mu_k^* = \sum_{i=1}^{n} \left(x_i - m_k^* \right)^k / n, \text{ where } k = 2,3,,.... \quad (2)$$

It should be noted that sample moments (1) and (2) for large sample sizes are unbiased and efficient estimates of the corresponding moments of the distributions, and provided that $n \to \infty$ are also consistent and asymptotically normal. It is known that the most complete characteristic of any sample ($x_1, x_2, ..., x_n$) is not the moments of the distribution but the sampling distribution itself [41]. However, the use of the sampling distribution of GE DP is inconvenient for EO. Therefore, various numerical measures of distribution indicators in the form of corresponding sample moments are more often used [42]. Assuming that the distributions of DP GE belong to the nonparametric family W, which are not known a priori, to identify their features in characteristic samples, we can use moments (1) and (2) of the first and second order (k=1, 2). The moments of the first and second order will characterize the mean and dispersion of the characteristic sample of GE DP values. In the case of Gaussian distributions, these moments will completely describe the distribution. But this does not mean that they cannot be used in the case of DP distributions other than Gaussian. For example, for a feature sample of DP, you can use the ratio of the square root of the sample second-order central moment (2) to the sample first-order moment (1). This ratio is usually called the sample coefficient of variation for the corresponding characteristic sample of GE DP values. Taking this into account, for a sample ($x_1, x_2, ..., x_n$) of an arbitrary GE DP of a fixed size, the sample coefficient of variation will be determined as:

$$KV = \sqrt{\sum_{i=1}^{n}\left(x_i - m_k^*\right)^2 / n} \Bigg/ \left(\sum_{i=1}^{n} x_i / n\right). \qquad (3)$$

It should be noted that for an arbitrary sample ($x_1, x_2, ..., x_n$) from the family W of Gaussian distributions, the measure of variation (3) will characterize the homogeneity of the sample – the measurement accuracy [43]. Therefore, the levels of measure (3) adopted in statistics relate specifically to the case of the Gaussian distribution. In the nonparametric case they are not suitable. It should be noted that measure (3) for a nonparametric family of distributions can be considered as a numerical characteristic of the noise/signal ratio of an arbitrary sample from a given family of distributions. This allows the use of measure (3) as a numerical indicator of the characteristics of the sample for various characteristic intervals of observation of the DP GE. It should be noted that this measure makes it possible to identify the most significant factors of the influence of F on the variation of the DP of the GE without revealing the real complex mechanisms of their influence. Therefore, measure (3) makes it possible to numerically evaluate the influence of F on the variation of various OPs of the GE. In this case, an important characteristic of measure (3) for application is the representativeness error. In general, as the sample size increases, the representativeness error of any sample measure tends to zero. Therefore, for the representativeness error σ_{KV} of measure (3), the following relation holds:

$$\sigma_{KV} = \frac{KV}{\sqrt{n}}\sqrt{1/2 + \left(KV/100\right)^2}. \qquad (4)$$

From (4) it follows that the representativeness error of measure (3) increases with increasing its value and decreases with increasing size of the sample used. Assuming that GE DP meters are characterized by measurement errors that are significantly smaller than error (4), we can consider measure (3) a reliable (with accuracy (4)) quantitative assessment of the degree of influence of F on various GE OPs. Measure (3) characterizes the deviation of the measured DP relative to its average value over the considered characteristic interval. If measure (3) is small, then this means that the deviations of the DP from the average value on the characteristic interval are close to the average value of the DP. Each subject area uses individual cutoff values for the coefficient of variation. For example, in biometrics it is generally accepted that deviations from the average value of less than 0.1 are weak and the average value will be a sufficient sample estimate for practice on the characteristic interval. Under this condition, the sample is considered homogeneous. If the values of the coefficient of variation are more than 0.1 and less than 0.25, then the deviations are considered average. With values of the coefficient of variation greater than 0.25, deviations are considered strong, and the sample is heterogeneous. Therefore, in the case of VZ, you can use the specified boundary values for measure (3) or determine its special values. In this case, it is necessary to determine the measure (3) of DP on the characteristic intervals of the reliable absence and appearance of F.

5. 2. Determination of the measure of variation in the parameters of the gaseous medium during the intervals between the absence and the beginning of ignition

As a result of the laboratory study, measures (3) and corresponding errors of representativeness (4) were determined for the main DP GE (CO concentration, smoke density, temperature) at two characteristic intervals (reliable absence (T0) and appearance of F (T1) TM). The results of the study are given in Table 1.

Table 1

Measures of coefficient of variation and representativeness error

No. of entry	GE DP/int	Alcohol	Paper	Wood	Textile
1	CO/T0	0.135	0.0026	0.0072	0.008
2	σ_{KV} CO/T0	0.0095	0.0002	0.00	0.0006
3	CO/T1	0.441	0.140	0.177	0.021
4	σ_{KV} CO/T0	0.0312	0.0099	0.0125	0.0015
5	D/T0	0.629	0.074	0.0085	0.0073
6	σ_{KV} D/T0	0.045	0.005	0.0006	0.0005
8	D/T1	0.805	0.013	0.0046	0.044
9	σ_{KV} D/T1	0.0569	0.000	0.0003	0.0031
10	T/T0	0.001	0.0019	0.0067	0.0033
11	σ_{KV} T/T0	0.0001	0.00067	0.0005	0.0002
12	T/T1	0.115	0.050	0.016	0.028
13	σ_{KV} T/T1	0.0081	0.0035	0.0011	0.002

In Table 1, the rows of representativeness error values for CO concentration are highlighted in yellow, in green – for smoke density, and in orange – for the GE temperature in the chamber at the corresponding intervals.

6. Discussion of results of the study of sample coefficients of variation for hazardous parameters of the gas environment during fires

From the analysis of the data given in Table 1, a number of important results for practice follow. The first conclusion concerns the representativeness error of the measure of the sample coefficient of variation of the DP GE at characteristic intervals. The magnitude of errors of representativeness on characteristic intervals for measures of the sample coefficient of variation of DP GE with a sample size of 100 is an order of magnitude smaller compared to the values of the corresponding measures. This means that the corresponding measure of the sample coefficient of variation fully reflects the characteristics of the general population at the selected characteristic intervals. Therefore, measure (3) with a sample size of 100 can be used as a quantitative indicator for identifying the features of the influence of F on the DP of GE.

The values of the measures of the sample coefficient of variation of the DP of the GE at characteristic intervals of the reliable occurrence of F of materials indicate, in general, an increase in measures compared to the absence of F. With F of alcohol, the value of the measure for the concentration of CO, smoke density, and temperature of the GE increases from 0.135 to 0.441, from 0.629 to 0.805, and from 0.001 to 0.115, respectively. In the case of paper F, the measure value for CO concentration and GE temperature increases from 0.0026 to 0.140 and from 0.0019 to 0.05, respectively. At tree F, the value of the measure for CO concentration and GE temperature increases from 0.0072 to 0.177 and from 0.0067 to 0.016, respectively. In the case of F of textiles, the value of the measure for CO concentration, smoke density and GE temperature increases from 0.008 to 0.021, from 0.0073 to 0.044 and from 0.0033 to 0.028, respectively. If we take into account the boundary values for the coefficient of variation adopted in biometrics, then it can be argued that in the characteristic interval of the absence of F (T0) samples of DP are characterized by weak deviations from the average value with the exception of samples of CO concentration (0.135) and smoke density (0.629) before F of alcohol. This means that before alcohol F, CO concentrations and smoke density are characterized by average significant deviations and, accordingly, average and significant inhomogeneities. The presence of moderate and significant heterogeneity of samples may indicate instability of the formation processes of CO concentration and GE smoke density in the chamber. It was found that the values of the measures of the sample coefficient of variation for smoke density in the case of F of paper and wood decrease. For example, with F of papers, the sample coefficient decreases from 0.074 to 0.013, and with F of trees, from 0.0085 to 0.0046. However, the indicated reduction in measures for smoke density is characterized by weak deviations, indicating the conditional homogeneity of the samples and the weak influence of wood paper F on the smoke density of the GE chamber. The decrease in the sampling coefficient at F of wood paper may be associated with obvious flaming combustion of materials, which is the reason for a slight decrease in the initial density of the GE smoke in the chamber. The greatest influence on the sampling of CO concentration, smoke density and temperature of the gas in the chamber is exerted by alcohol F. Moreover, this influence is manifested in a significant deviation of the sample values relative to the average value of the DP GE. This is explained by the fact that alcohol has a maximum specific burnout rate compared to other TMs. At the same time, the greatest sensitivity to F of HM is characteristic of DP in the idea of CO concentration. This sensitivity is manifested in the appearance of significant deviations of sample CO concentration values relative to the average. Thus, measure (3) allows us to study the features of the sample coefficient of variation of the DP of the GE at characteristic intervals of the absence and appearance of F of materials in the laboratory chamber. Results in Table 1 do not contradict known data [21, 44, 45].

Our results make it possible in practice to indicate a real way to solve the problem of fires at the stage of their early occurrence due to the difference in the measure of the sample coefficient of variation of the DP GE of the room at the intervals of the absence and appearance of fires. At the same time, the limitations of the study include the given set of TM and DP GE in the chamber. The disadvantage of the study is the impossibility of using the proposed approach for the temporary localization of the beginning of F of materials. Elimination of these limitations and shortcomings can be carried out by expanding the range of TMs and OPs, conducting fire tests, as well as modifying the proposed approach. The development of the research is expected in the directions of overcoming the noted limitations and disadvantages.

7. Conclusions

1. A substantiation of the sample coefficient of variation measure for an arbitrary dangerous gaseous medium parameter observed over an arbitrary fixed time interval has been carried out. The representativeness error of the sample coefficient of variation measure is determined, which depends on the size of the measure and the size of the attribute sample. This makes it possible to numerically characterize the features of the sample coefficient of variation of an arbitrary dangerous parameter of the gaseous environment at various characteristic observation intervals. The measure of the sample coefficient of variation at characteristic intervals of observation of a dangerous parameter of the gaseous environment makes it possible to numerically determine its features for each of the intervals. In the case of characteristic intervals of observation of a dangerous environmental parameter, corresponding to the reliable absence and appearance of a fire, it makes it possible to identify the fact of the occurrence of a fire by the difference in measures at the specified intervals.

2. Experiments were conducted to determine measures of the sample coefficient of variation for the reliable absence and appearance of fire. The results obtained indicate that the parameters of the gas environment in the intervals of the absence and presence of fires are characterized by different values of the measures of the sample coefficient of variation. Moreover, the values of this measure at intervals of reliable occurrence of fires indicate their increase compared to the absence of fires. It has been established that the ignition of alcohol causes a maximum increase in this measure for CO concentration (from 0.135 to 0.441), for smoke density (from 0.629 to 0.805), and for temperature (from 0.001 to 0.115). In the case of paper burning, the measure for CO concentration and GE temperature increases from 0.0026 to 0.140 and from 0.0019 to 0.05, respectively. When a tree burns,

the measure for CO concentration and GE temperature increases, respectively, from 0.0072 to 0.177 and from 0.0067 to 0.016. In the case of textile fires, the measure for CO concentration, smoke density, and GE temperature increases from 0.008 to 0.021, from 0.0073 to 0.044, and from 0.0033 to 0.028, respectively.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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