Empirical cumulative function of distribution studies of the dynamics of state the gas medium in the fire heat sources occurrence

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A technique empirical cumulative distribution function of the dynamics of increments of the state vector of the gaseous medium is substantiated. The technique is bussed on non-recurrence of increments of the state vector. Explored function on intervals for before and after a heat source fires.

Keywords – empirical cumulative distribution function, gaseous medium, increments of the states, heat sources of fire.

Introduction

Fires are one of the factors that violate the sustainability of the development of civilization. Fires cause significant damage not only to people, but also to the environment. The number of fires in the world has a hazardous trend of annual growth. About 90 thousand people die each year [1]. Therefore, the prevention of fires is one of the urgent problems of any state. It is known that hazardous acid rain and pollution of aquifers may result from a fire. Therefore the identification of hot spots before their transition into fires is one of the important problems of modern times.

I. Literature review and problem statement

From the analysis of the modern literature, it follows that the dynamics of hazardous parameters of the gaseous environment (GEP) in the event of a fire from various heat sources have a complex nonlinear, and chaotic character, depending on many uncertain random factors. Currently, various methods are known for identifying heat sources. Most of the methods are complex, have limited sensitivity and efficiency on identifying heat sources of fire. Methods of non-linear dynamics [2] should be considered the most constructive of those known for identifying heat sources based on the dynamics of hazardous parameters of the GEP. However, at present, there are no articles that would consider methods for identifying heat sources of fire, based on a selective cumulative distribution function of increments in the state of the gaseous environment of premises. These methods, being non-parametric, make it possible to identify heat sources of fire under conditions of great uncertainty. Therefore, an important and unsolved part of the problem of identifying heat sources of fire is the lack of studies on the selective cumulative distribution function of the dynamics of increments in the GEP state when such sources appear.

II. The aim and objectives of the study

The aim of the work is to study the empirical cumulative distribution function of the dynamics of increments in the state of the GEP when heat sources of fire appear in the room. The results of the study will allow in practice to quickly detect the appearance of heat sources of fire and prevent the occurrence of a fire in real conditions.

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

– theoretically substantiate the methodology for studying the empirical cumulative function of the distribution of the dynamics of increments in the state of the GEP when heat sources of fire appear in the room;

– to investigate the empirical cumulative function of the distribution of the dynamics of increments of the state of the GEP at two fixed time intervals before and after the appearance of test heat sources of fire in the laboratory chamber.

III. The study materials and methods

The research materials include measurements of dangerous parameters of the state of the gaseous medium in a laboratory chamber for various heat sources fire – alcohol, wood, cellulose, and textiles [3]. Smoke density, mean volume temperature, and carbon monoxide concentration were measured [4]. The measurements were carried out at discrete times i=0, 1, 2, ,...., 400. The interval between discrete measurements was 0.1 seconds. The set of dangerous parameters at the moment number i determined the vector xi of the state of the gaseous medium at the moment i. The smoke density was measured TGS2442 sensor (Japan), the average volume temperature was measured with a DS18B20 (Germany), and the carbon monoxide concentration was measured with an MQ-2 (China). Ignition of test heat sources in the chamber was carried out 20 – 25 seconds after the start of measurement. Research methods were based on the representation of the gaseous medium as a complex dynamic system. The state of such a system depends on many unknown parameters and factors. For example, on the parameters of a heat source, a room, as well as various interfering factors. The probabilistic properties of state increments of the gaseous medium are studied by the method of sample cumulative distribution function [5].

IV. Substantiation of the methodology for studying the empirical cumulative distribution function of the dynamics of increments in the state of the gaseous medium

The technique is based on the representation of the state of the gaseous medium in the form of a random event associated with the appearance of a heat source of the fire. This random event is the result of many random causes. The laws of operation of these causes are usually unknown. Therefore, it is impossible to predict in advance whether a given event will or will not occur. However, when measuring the state of a gaseous medium, that event is associated with the appearance of a real random variable. For example, it can be the state vector of the gaseous medium itself or its increments [3]. From a probabilistic point of view, any random event is completely described by the integral probability distribution function of random variables associated with this event. In English-language literature, the integral probability distribution function is often called the cumulative distribution function. The technique includes sequential execution of seven procedures. The first procedure is to measure the hazardous parameters of the GEP. This procedure is carried out using measuring sensors. Based on the measurement results, each sensor generates the current values of the GEP state vector x_i, where i=0, 1, 2, ..., Ns–1, Ns – the maximum number of discrete measurements performed by each of the sensors. The second procedure includes the generation of the state vector x_i the increments $z_i = x_i - x_{i-1}$ for each discrete moment of time. The third procedure is to determine the space Ω of increment vectors $z_i \subset \Omega$ and the metric $d_{i,j}$ for that space. The metric $d_{i,j} = |z_i - z_j|$ determines the distance between an arbitrary pair of elements of the space Ω. The fourth procedure includes the determination the function $R(i,j,\varepsilon) = \text{if}\{i \neq j, ZH(\varepsilon - d_{i,j}), 0\}$ for pairs of (similar or recurrent) elements of the space Ω, for which the metric $d_{i,j}$ is less than a given value ε. Were function $ZH(x) = \text{if}\,(x \leq 0,0,1)$ is determination characteristic function. The fifth procedure consists in calculating for each moment i and a given value ε of the function:

$$\mathrm{TDR}\,(i,\varepsilon) = if\,\{i < 0, 0, \frac{1}{i+1}\sum_{k=0}^{i} R(i, i-k, \varepsilon)\} \tag{1}$$

Function (1) determines the sample probability of recurrence (similarities with the accuracy of the value ε) for increments of the state vector of the gaseous medium up to the moment i inclusive. The sixth procedure is to determine the current probability of the opposite event – the probability of non-recurrence (dissimilarity) of the increments of the state vector of the gaseous medium. This probability is calculated based on (4), following the expression:

$$\mathrm{TDNR}\,(i,\varepsilon) = 1 - \mathrm{TDR}\,(i,\varepsilon) \tag{2}$$

The seventh procedure is to calculate the sample cumulative distribution function based on (2), for an arbitrary interval of measurement moments $i \subset (NI, NI + TI)$. The value NI defines the beginning of the given interval, and TI defines the duration of this interval. The sample cumulative distribution function for a given level y and interval $i \subset (NI, NI + TI)$ is determined by the formula:

$$\mathrm{F}(y,\varepsilon) = \frac{1}{TI}\sum_{l=NI}^{NI+TII} ZH\{(y - TDNR(l,\varepsilon)\} \tag{3}$$

Calculation of the sample cumulative distribution function (3) allows one to study the features of the dynamics of the probability of non-recurrence (dissimilarity) of increments of the state vector of the gaseous medium. Thus, the described technique includes the execution of a sequence of calculations (1) – (3) based on measurements of dangerous parameters of the gaseous medium and allows us to study the selective cumulative distribution function of the dynamics of increments of the state vector of the gaseous medium for arbitrary time intervals. This allows the sample cumulative distribution function to be used to detect heat sources fire in a room in real time.

V. Results of the study of the empirical cumulative distribution function of the dynamics of increments of the state vector of the gaseous medium

The studies were carried out on the basis of experimental measurements of dangerous parameters of the gaseous medium in a laboratory chamber for test heat sources the fire. The measurements were performed on two different time intervals before and after the appearance of test heat sources the fire in the laboratory chamber. The duration the intervals, was determined

100 discrete measurements. The beginning of the first interval was determined 100-th discrete measurement. The beginning of the second interval was determined 200-th discrete measurement. These intervals were determined by the reliable absence and presence of a heat source the fire in the chamber. Obtained empirical cumulative distribution functions of the probability dynamics of non-recurrence (dissimilarity) of increments of the state vector of the gaseous medium over the studied intervals fire of alcohol, cellulose, wood and textiles, corresponding the value $\varepsilon = 0{,}01$. The results take into account real errors in measurements by sensors of dangerous parameters of the gaseous medium in a laboratory chamber. The sensors applied in the experiment are used in existing fire detectors. Therefore, the results obtained can be considered reliable.

VI. Discussion of the results of the study

The research results are explained by the complex nature of the real dynamics of the vector of increments of the state of the gaseous medium in the laboratory chamber for test heat sources of fire. Following the results, the possible values of the empirical cumulative distribution function of the probability dynamics of non-recurrence (dissimilarity) of the increments of the state vector of the gaseous medium in the chamber in the absence and presence of heat source of fire have different values. For example, the lower bound, for non-recurrence probability values are different. For alcohol, this lower bound is determined by the probability values in the region centered at 0,5. For cellulose, wood, and textiles, this boundary is defined by areas centered at 0,35, 0,27, and 0,4, respectively. Such a scatter of boundaries is explained by the different quality of the restoration of the state of the gaseous medium in the chamber after each study. Cumulative distribution functions have characteristic areas of increase and constancy of functions. The main feature of the cumulative distribution functions in the case of the appearance of test heat sources of fire is the decrease in the probability value for fixed sections of function values compared to the case of the absence of heat sources. For example, for alcohol this probability decreases from 0,58 to 0,15, and for cellulose from 0,61 to 0,29. For wood this probability decreases from 0,71 to 0,28, and for textiles from 0,68 to 0,44. Following the well-known property of cumulative distribution functions, for intervals of fixed values the probability that the random variable under study falls into these intervals is equal to zero. This means that the values of the probability of non-recurrence for alcohol and cellulose in the ranges from 0,53 to 0,9 and from 0,39 to 0,9, respectively, are equal to zero. The values of the probability of non-recurrence for wood and textiles are equal to zero in the intervals from 0,33 to 0,93 and from 0,45 to 0,85, respectively. Areas of increasing cumulative distribution functions in define those possible intervals of non-recurrence probability values for which the probability is non-zero. This probability is determined by the difference between the values of the corresponding cumulative distribution function at the boundary points of the interval of non-recurrence probabilities that are different from zero. Thus, the features of the empirical cumulative distribution functions of the probability dynamics of non-recurrence (dissimilarity) of increments of the state vector of the gaseous medium when thermal fire sources appear allow early fire detection. The main sign of this is the decrease in the values of the empirical cumulative distribution function on fixed sections of functions. For the studied test sources of the fire the values of the empirical cumulative distribution function on fixed sections of functions lie in the range from 0,15 to 0,44. The minimum value of 0,15 is typical to the heat source of the fire in the form of alcohol. The maximum value of 0,44 is typical for source fire in the form of textiles. This is explained by the fact that these sources fire have a maximum and minimum ignition rate of the material. The limitations of the study include a finite set of test sources of fire and the use of experimental data parameters of the gaseous environment in the laboratory chamber.

Conclusions

A method for studying the empirical cumulative function of the distribution of the dynamics increments of the state vector the GEP with the appearance of heat sources of fire is substantiated. The technique includes the implementation of seven sequential procedures. Sequential execution of these procedures makes it possible to investigate the sample cumulative distribution function of the probability dynamics of the non-recurrence of increments of the state vector of the gaseous medium. This makes it possible to use a sample cumulative distribution function for early detection of sources of fire in a room. The empirical cumulative distribution function of the probability dynamics of non-recurrence of GEP state vector increments on two fixed time intervals of equal duration was studied. The studies were performed for two time intervals – before and after the appearance of test heat sources of fire in the laboratory chamber. It has been established that the features of the empirical cumulative distribution functions of the probability dynamics of non-recurrence (dissimilarity) of increments of the state vector of the gaseous medium allow early detection of a fire. The main sign of this is the decrease in the fixed values of the empirical cumulative distribution function. It is determined that for test heat sources of fire, the values of the empirical cumulative distribution function (for fixed areas) lie in the range from 0,15 to 0,44. These probabilities are determined by different ignition rates of test heat sources of fire. In general, the research results indicate the possibility of using the features of empirical cumulative distribution functions of the probability dynamics of non-recurrence (dissimilarity) of increments of the state vector of the gaseous medium at different intervals for early detection of a fire.

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