

Fire alarm systems construction on artificial intelligence principles

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Abstract. Coverage of modern views on security trends and directions for developing security systems in the context of global automation and integration into unified automated control systems. An overview of the prospects for using artificial intelligence in security systems to identify difficult to classify situations using signs obtained from monitoring data. Assessment of the prospects for the use of fire alarm systems based on the principles of artificial intelligence based on neural networks (building on the principles of combinatorics of methods of neural networks and odd logic systems). Construction of a mathematical model that describes the process of generating a reliable formation of a signal about the transition of the system to the "fire" state and a description of the problem of correctly setting the system response threshold for signal generation, solving the problem of minimizing the number of false positives by introducing an additional channel that receives initial information about the state of the object in the optical range. Investigation of the reliability of the characteristics of gas fire detectors declared by the manufacturer to determine the possibility of using them as initial elements of fire alarm systems built on the principles of neural networks.

1 Introduction

The trends in the modern development of security systems are inextricably linked with the processes of wide automation and integration, which concern not only security systems but also all systems designed to automate the management of life support and the functioning of a residential building, office, enterprise, or other facilities. The logical development of such integration was the creation of integrated security systems (ISS) with broad functionality that allows automation of the management of engineering systems of a building or facility [1-4]. In all countries, the requirement for fire alarm systems (FAS), which are a mandatory element when any building (structure) is put into operation, is regulated [5].

2 Materials and methods

2.1 Mathematical, empirical, and theoretical

One of the most promising areas for designing integrated fire alarm and evacuation control systems is using artificial intelligence (AI) elements based on trained neural networks (NN) principles. NN are a complex system of connected and interacting simple processors (artificial neurons). Each processor receives and transmits signals to other processors, which allows for solving complex problems. [6] The article's authors proposed a scientific hypothesis about the possibility of using NN for pattern recognition and solving problems of classifying fires by visual features. Mathematical, empirical, and theoretical methods were used as research methods.

AI is most suitable for classifying difficult situations using signs obtained from object monitoring data (smoldering, combustion, etc.). For example, AI can determine a set of special characteristics or features of various fire situations using the collected data and apply them to decision-making in real fire situations. One of the main properties of NN is the ability to learn. This property allows AI-based FAS to increase the reliability of the assessment of various fire situations by optimizing the functional weights and parameters of the algorithms. Learning is a process in which the parameters of a NN are tuned by simulating the environment (such as a fire seat) where the network is embedded. However, learning algorithms are difficult to adapt to dynamic changes, which include the combustion process, since the values of the variables are fixed after the learning process. [7-10].

The block diagram of the learning process of the NN FAS is shown in Fig. 1.

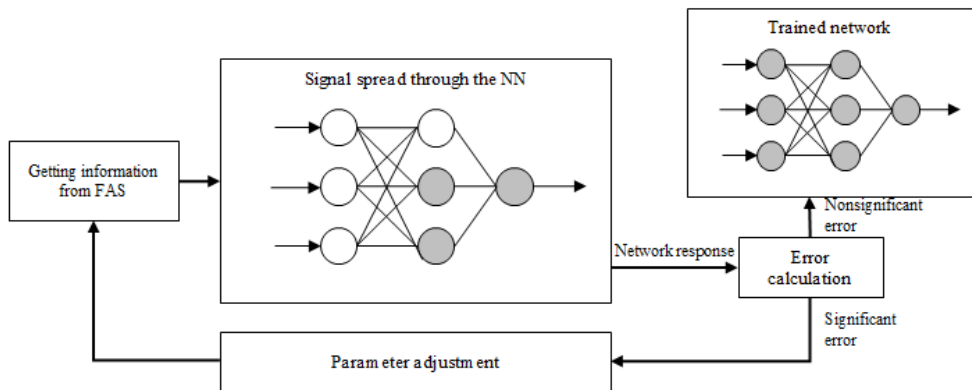


Fig. 1. NN training scheme

The analysis of scientific works in AI allows concluding that this area of research is the most promising in the engineering of FAS because the sampling system is random and depends on many weakly correlated factors [11-13].

The FAS state has 4 possible states, random events, and the system states are characterized by conditional probabilities in Table 1.

Table 1. FAS states

| fire (λ) actuation threshold (Y) | 0 | 1 |
|---|----------------------------------|-------------------------------|
| 0 | system in initial state P_b | omission P_o |
| 1 | false alarm P_{fa} | correct detection P_{cd} |

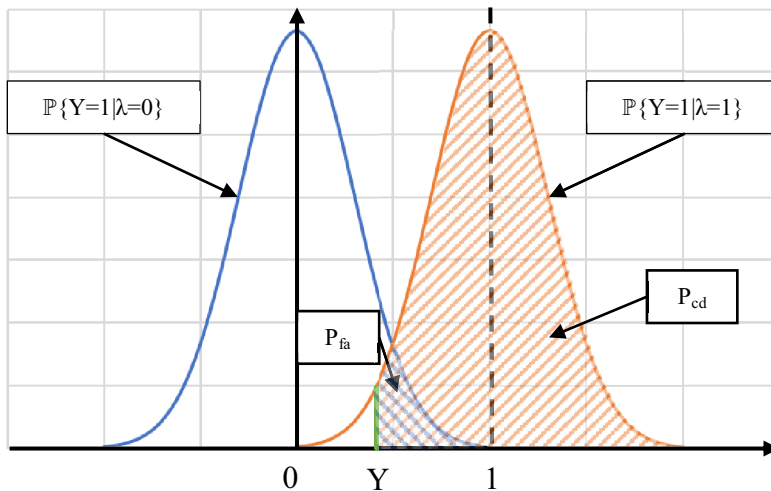
In pairs, events characterizing the state of the system constitute a complete group of events; the probabilities are:

$$\begin{cases} P_b + P_{fa} = 1 \\ P_o + P_{cd} = 1 \end{cases}$$

Accordingly, the probabilities of correct operation and false operation can be described by the expressions:

$$\begin{aligned} P_{cd} &= \mathbb{P}\{Y = 1 | \lambda = 1\} = \textit{Detection} \\ P_{fa} &= \mathbb{P}\{Y = 1 | \lambda = 0\} = \textit{False} \end{aligned}$$

A graphical representation of the probability distributions of the states in which the FAS is located: "correct actuation" and "false actuation," are shown in Fig.2. [14-16] It follows from the graph that an increase in the value of the actuation threshold Y leads to a decrease in the probability of a false alarm. However, this increases the probability of failure of the alarm in case of a fire at the facility. Thus, there is a problem with setting the correct actuation threshold value. One of the approaches to solving this problem is creating an additional verifying control channel, which is graphically explained by a decrease in the dispersion of distributions that characterize the probabilities of "correct actuation" and "false actuation" [17, 18].

**Fig. 2.** Graphical representation of the probability distributions of states

In FAS, the actuation threshold Y is set at the setup stage and remains unchanged during operation. Threshold changes can be made during periodic maintenance or as needed.

Summarizing the above, one of the tasks in training the NN is the constant adjustment of the response actuation threshold depending on the situation at the facility, which technically comes down to a verification procedure, which is aimed at determining the correctness of the equipment settings and evaluating the correctness of the received data, and establishing the requirements for their implementation.

2.2 Initial data for the experiment

There are many different gas fire detectors on the market. Therefore, there is a problem with correctly estimating their parameters and selecting sensors suitable for use in NN training. For example, the following sensors of the MQ series are offered for sale: a wide range of gases MQ-2; alcohol vapor MQ-3; natural gas MQ-4; combustible gases MQ-5; liquefied petroleum gases MQ-6; carbon monoxide MQ-7; hydrogen MQ-8; combustible and carbon monoxide MQ-9. [19] In the article, gas fire detectors based on a tin dioxide sensor of types MQ-2,4,9 are considered the end device of the FAS. In the Russian Federation, the requirements for this type of detector are regulatory ones following Russian State Standard GOST R 53325-2012 Fire fighting equipment. Technical means of fire automatics. General technical requirements and test methods.

The considered series of sensors refers to semiconductor devices, the principle of operation of which is based on a change in the resistance of a thin-film layer of tin dioxide SnO_2 upon contact with the molecules of the defined gas. The sensitive element of the sensor consists of a ceramic tube coated with Al_2O_3 and a sensitive layer of tin dioxide deposited on it. A heating element passes inside the tube, which heats the sensitive layer to a temperature at which it begins to react to the defined gas. Sensitivity to different gases is achieved by varying the composition of impurities in the sensitive layer. To compare the characteristics of the sensors, we propose to use the parameter - concentration in ppm, which characterizes the ratio of one gas to another.

3 Research results

The problem solution of comparative evaluation of the selected indicators is carried out experimentally to clarify the correctness of the declared technical characteristics. The logic of the experiment is conditionally divided into several stages. The first stage is connecting the sensor to the software microcontroller and heating the sensor following the technical regulations. The second one is filling the experimental chamber with a fixed concentration combustion products. The third one is installing the sensor in the chamber, excluding the change in the concentration of combustion products. The fourth is reading and processing data. The fifth is removing the sensor and fixing the return time to its initial state. The sixth is the ventilation of the smoke chamber after each measurement. For correct statistical processing of data, it is advisable to carry out at least 10 measurements for each type of sensor, followed by mathematical data processing by averaging the readings.

The declared characteristics of the sensors specified in the accompanying technical documentation in open sources were previously studied. As a result of the experiments, the received data were summarized in a table for comparison with the declared ones (Table 2).

Table 2. Comparative characteristics of sensors

| | Sensitivity range, ppm | | |
|--------------|------------------------|-----------|----------|
| | MQ-2 | MQ-04 | MQ-9 |
| Declared | 200-20000 | 200-10000 | 20-10000 |
| Experimental | 325-888 | 99-386 | 30-330 |

From the data in Table 2, the conclusions follow that the experimental values differ from those declared by the manufacturer. The received data are within the declared range; however, the upper limit of the sensitivity range is much less than the declared one. Based on this, we can conclude that the incorrect operation of the sensor in conditions of an avalanche-like increase in smoke concentration can affect the efficiency of the FAS in real conditions. Thus, the probability of correct operation of the FAS is reduced, requiring additional channels to identify the fire phenomenon. [20-23]

The experiment results are displayed in graphical form for a visual presentation of the data. The experimental data show the dependence of the sensor resistance in clean air (R_0) and the sensor resistance in the presence of gas in the smoke chamber (R_s); they are presented in Fig. 3.

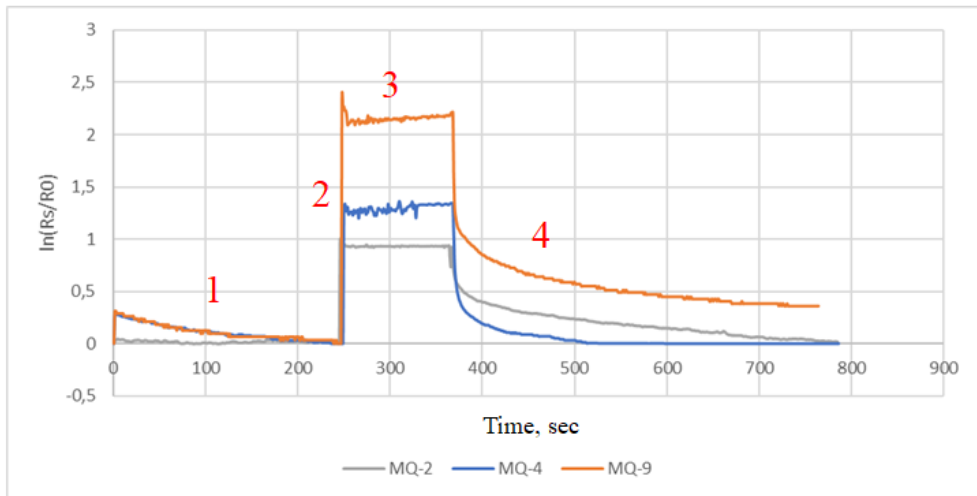


Fig. 3. Results of the experiment

The type of dependence is identical for different sensors and is characterized by four conditional sections: 1 is sensor calibration, 2 is actuation, 3 is working state, 4 is return to the initial state. The type of graphic dependence can be approximated by a meander and is described by the following mathematical dependence.

$$x_{\text{меандр}}(t) = \frac{4}{\pi} \sum_{k=1}^{\infty} \frac{\sin(2\pi(2k - 1)ft)}{2k - 1}$$

A straight line can approximate the first section; the second section is a vertical front without "blockages"; the third section is the top described by a straight line, a filtering procedure can be applied to exclude fluctuations; the fourth section is the most interesting, it can be approximated by an exponential dependence.

$$f(x) = \begin{cases} ax + b, & 0 \leq x < t_0 \\ c, & x = t_1 \\ dx + g, & t_2 \leq x < t_3 \\ \exp(h + kx), & t_4 \leq x < t_5 \end{cases}$$

Where: a,b,c,d,g,h,k are correction coefficients, t_i is time intervals.

For example, the value of the coefficients for the MQ-2 sensor will be as follows:

| a | b | c | d | g | h | k |
|---------|--------|-------|--------|--------|---------|----------|
| -0.0125 | 333.08 | 888 | 0.0274 | 819.85 | 6.58027 | -0.00104 |
| 0 | t_0 | t_1 | t_2 | t_3 | t_4 | t_5 |
| 0 | 245 | 246 | 246 | 364 | 365 | 820 |

The correlation of the experimental data approximation results is shown in Figure 4

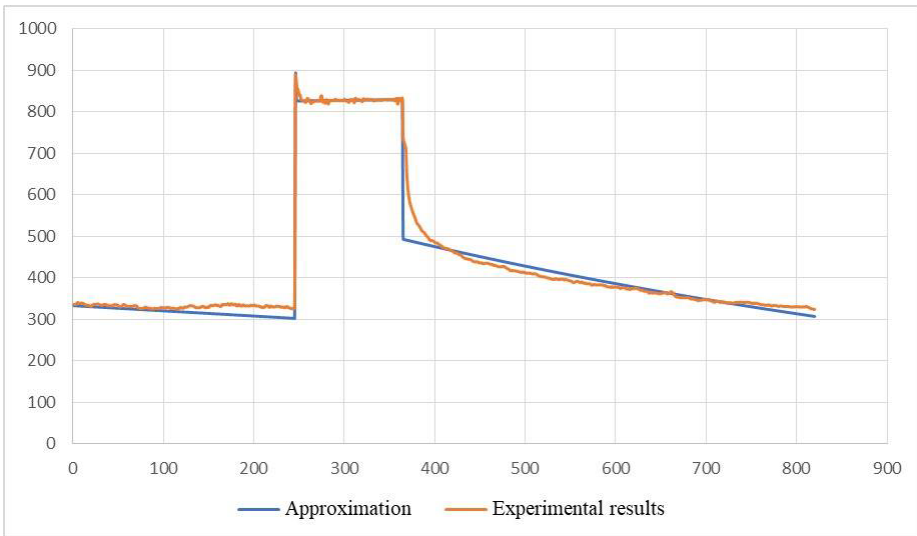


Fig. 4. Approximation of the experimental results

The curvature of the exponent characterizes the transition time of the sensor to the initial state. The duration of the transition process affects the time the FAS is in an indeterminate state and cannot correctly perform functional tasks. For example, the sensor readings indicate that the fire continues (the values from the sensor are higher than the lower actuation threshold value) while, in fact, the fire has already been eliminated. To estimate the transition time to the initial state, you can use the mathematical description of non-stationary processes in electrical circuits.

4 Conclusion

Thus, the analysis of the obtained results allows drawing the following conclusions. To minimize the false alarm of FAS, a verification channel is needed. This channel will receive initial information about the object's state in the optical range. According to the execution of the end device, the principle of the channel operation can be as follows: constant monitoring by the object state operator through surveillance cameras or using technical

devices. The first option is traditionally implemented; however, considering the "human factor" in ensuring fire safety is a difficult task to formalize.

It is proposed to consider the possibility of using a technical device as an end device that implements the principles of the NN. The construction of FAS exclusively with gas fire detectors is impractical because the reliability of the information received about a fire is determined by the sensor specification and the instability of the declared characteristics spread.

A study on this topic was previously conducted at the Higher School of Technosphere Safety of the SPbPU (Institute of Civil Engineering). For this, an experimental facility of "Holding Gefest" LLC was involved. The authors carried out the research with the permission of the company's management. The materials presented in the article are preliminary and require additional research and correction.

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