OPTIMIZATION OF FIRE ALARM SYSTEMS BASED ON EVOLUTIONARY METHODS

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Abstract: *The formalized raising of task of optimization of structure of the system of the fire monitoring is executed. Objective functions are worked out for apartments with the sources of enhanceable fire hazard, with the uneven fire loading and for a general case. The method of search of optimal structure of fire sensors is offered on the basis of evolutional design.*

Keywords*: evolutional design, objective function, monitoring.*

ACM Classification Keywords*:* I.2.1 Applications and Expert Systems*.*

Introduction

The last decade marked by a relatively constant annual number of fires and trend growth in the number of those killed and injured, and the amount of material losses. Not least, this fact is due to low efficiency of fire and automation, including fire detection systems - fire alarm systems. Despite the fact that a number of quantitative indicators of such systems to CIS countries and Ukraine, in particular, the group leading the world, quality indicators that reflect the level of technical solutions in this area in the CIS countries on one or two orders of magnitude is lower than in the world.

In particular, the world's main development conducted by the Office for Research in Construction (BRE, UK), Laboratory of Building and Fire Research (BERL, USA), Institute of Fire Research (FRI, Japan), FGU VNIIPO of EMERCOM of Russia and others. In Ukraine, on a similar theme running Ukrainian Research Institute of Fire Safety Ministry of Ukraine, and many firms as a "Meridian", "Arthon", "Tiras", "Gamma".

The vast majority of these studies dealt with only one element Signalling - the detector and its improvement. Beyond consideration of the remaining problems of the optimal structure fire alarm system of "binding" to a particular item. Neglecting its features, the use of standard approaches and regulatory requirements leads to an increase in casualties, volume losses, as well as false positives. And the main reason for such negative effects is to increase the time fire detection inefficiency due to fire alarms.

The objective is to optimize fire alarm system through the development and use of models that will determine the number and placement of the structure fire detectors using an evolutionary simulation.

Problem

Let the number of detectors are available N . Horizontal areas of responsibility overlap, forming a region Ξ_i with different multiplicity detectors responsibility, $i = \overline{1, k_\Xi}$, where k_Ξ - number of areas. Known as the target function [1] and problem

$$F(W) = F(X,Y) = \sum_{i=1}^{k_\Xi} \frac{1}{p_c^i} \cdot t_c^i \to \min, \tag{1}$$

where W - the structure of the detectors $X=(x_1,x_2,...,x_N)$, $Y=(y_1,y_2,...,y_N)$, (x_i,y_i) - the coordinates of the detector, $i=\overline{1,N}$, p_c^i - the probability of operation of the detector or detectors in a fire based redundancy, t_c^i - the average time from the beginning of the fire that occurred at the point region Ξ_i by the time the detector response time.

Optimization of placement of detectors based on genetic algorithm

It is known that the structure of the detectors is determined by the set of coordinates of their location. To install this set to be the solution of problem (1), we use elements of the genetic algorithm (GA) [3]. According to the GA steps necessary to form a general set of potential solutions. Assume that they all belong to the field $\Xi = \{(x_1,x_1)/\, x_1 \in [0,a], x_2 \in [0,b]\}$. The number of potential solutions n by setting up resolution of the problem (1). Assume that the specified accuracy of solution on the axis x_1 and axis x_2 - ε_1 and ε_2. Traditionally impose $\varepsilon = \min\{\varepsilon_1,\varepsilon_2\}$ and further ε considered accurate result. Then the area Ξ is divided by horizontal and vertical lines, forming a square the side ε. Their peaks and will determine the general population of potential solutions. We propose a modified way. In determining the set of potential solutions will take into account that the room is rectangular in shape with sides a and b Then find $c = \max\{\frac{a}{\varepsilon_1},\frac{b}{\varepsilon_2}\}$. And if $c = \frac{a}{\varepsilon_1}$, the distance between lines is equal ε_1, otherwise - ε_2. But this separation inevitably creates redundancy information, as part of the solutions outside the region Ξ. In many cases, redundancy can be avoided $\varepsilon = НОД(\varepsilon_1,\varepsilon_2)$. Then put the number of potential solutions will be

$$\left(\left[\frac{a}{\varepsilon}\right]+1\right)\cdot\left(\left[\frac{b}{\varepsilon}\right]+1\right)-2\left(\left[\frac{a}{\varepsilon}\right]+1\right)-2\left(\left[\frac{b}{\varepsilon}\right]+1\right)+4=\left[\frac{ab}{\varepsilon^2}\right]-\left[\frac{a+b}{\varepsilon}\right]+1.$$

The encoding potential solutions of binary numbers to consider a different number of bits to encode the ordinates and abscissas solution. To reserve ordinates $\left[\log_2\frac{a}{\varepsilon}\right]+1$ digits for abscissas - $\left[\log_2\frac{b}{\varepsilon}\right]+1$ digits. Structure solution is:

$$X=(X_1,X_2,...,X_n)=(x_1^1,x_2^1,x_1^2,x_2^2,...,x_1^n,x_2^n)=(\overbrace{\underbrace{00111..1}_{[\log_2\frac{a}{\varepsilon}]+1\ digits}}^{x_1^1}\overbrace{\underbrace{10110..0}_{[\log_2\frac{b}{\varepsilon}]+1\ digits}}^{x_2^1}\ \overbrace{\underbrace{00110..0}_{[\log_2\frac{a}{\varepsilon}]+1\ digits}}^{x_1^2}\overbrace{\underbrace{01011..1}_{[\log_2\frac{b}{\varepsilon}]+1\ digits}}^{x_2^2}...\overbrace{\underbrace{10101..1}_{[\log_2\frac{a}{\varepsilon}]+1\ digits}}^{x_1^n}\overbrace{\underbrace{01110..0}_{[\log_2\frac{b}{\varepsilon}]+1\ digits}}^{x_2^n})$$

Thus defined the general population of potential solutions. The number of its elements is

$$2^{n\left(\left[\log_2\frac{a}{\varepsilon}\right]+1\right)}\cdot 2^{n\left(\left[\log_2\frac{b}{\varepsilon}\right]+1\right)} = 2^{n\left[\log_2\frac{ab}{\varepsilon^2}\right]+2n}.$$

This number is large and even at the present level of development of computer technology to solve practical problems by exhaustive search is often impossible.

That is why you need to select a custom set of solutions. Its capacity ranges from 10 to 50 elements. Fewer solutions minimizes "genetic diversity" sample and considerable time finding the solution. Otherwise, however, "diversity" is present in full, but the complexity of calculations than even the first time.

To form the sample to realize the mapping

$$\{(x_i, y_i) / x_i, y_i \in R\} \leftrightarrow \{(x_i, y_i) / x_i, y_i \in Z^+\} \leftrightarrow$$
$$\{(x_i, y_i) / x_i, y_i \in B\},$$

where - R the set of real numbers, Z^+ - the set of integral whole numbers, B - a set of binary numbers.

Assuming without loss of generality that the number of elements of the sample 20, play the 20 pairs of random numbers (x_1^i, x_2^i), where

$$x_1^i \in \left\{0,1,2,...,\left[\frac{a}{\varepsilon}\right]+1\right\},\ x_2^i \in \left\{0,1,2,...,\left[\frac{b}{\varepsilon}\right]+1\right\},\ i=\overline{1,20}.$$

An important step is the formation of the target function [4]. We use the target function of problem (1). Then to determine the parameters p_c and t_c. Note that the objective function somehow simplified because it does not need to analytically determine the zone of responsibility of different multiplicity detectors.

Number the elements of the sample and then they can be written as a trio $(X_1^i, X_2^i, n(i)=i), i=\overline{1,20}.$ Then in order to avoid possible bias, make the following steps. Generate a sample of possible points of fire. Power depends on sample size of the room. Again, without limiting the generality, suppose that the following points 10: $(y_1^i, y_2^i), m(i)),\ i=\overline{1,10}$. Let us form the matrix of distances from points of fire for fire detectors

$$D = \begin{pmatrix} d_{1\,1}\ d_{1\,2}\ ...d_{1\,20} \\ d_{2\,1}\ d_{2\,2}\ ...d_{2\,20} \\ ------ \\ d_{10\,1}\ d_{10\,2}\ ...d_{10\,20} \end{pmatrix},$$

where $d_{ij} = \sqrt{(y_1^i - x_1^j)^2 + (y_2^i - x_2^j)^2}, i=\overline{1,10}, j=\overline{1,20}$.

The radius of the cone base area of the detector consider known and equal r. Obviously, the average time from start fires that occurred in the area of responsibility of the detector, the time of its operation depends on the distance from the point of fire to coordinate horizontal and the detector is located directly on the matrix D (Fig. 1). Make use of the fact that appropriate time is directly proportional to distance. We consider also a known probability p of correct operation of the detector. Then, to i-th point of fire to find value $v_i = \sum_{j=1}^{20} \chi\left(d_{ij} < r\right), i=\overline{1,10}$. The appropriate value $p_c{}^i = 1-(1-p)^{v_i}$.

Thus, the modified objective function will be the

$$F(w) = \sum_{i=1}^{10} \frac{1}{1-(1-p)^{\sum_{j=1}^{20}\chi(d_{ij}<r)}} \cdot \min_j d_{ij}. \qquad (2)$$

Formation of the objective function (2) completed preparatory operations to find its minimum by using GA. But, as discussed above, the choice of one possible set of points of fire, including fire load balancing facilities, leading to displacement of the solution.

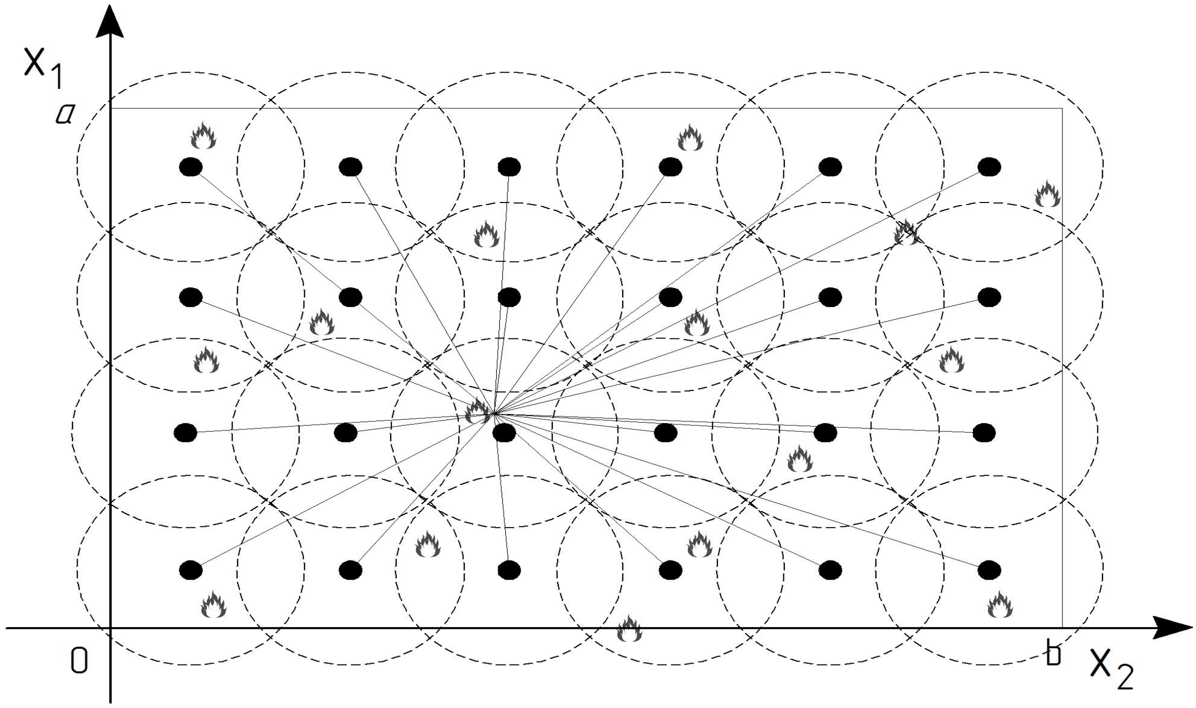

Fig. 1. Placement of detectors and possible points of fire

Will make some changes to the method of finding the optimal placement of fire detectors. The method will have several such stages. The first of them generate a sample of potential points of fire A_1^1 and find the corresponding optimal placement of detectors. In the second phase generate two samples A_1^2 and A_2^2, and again we find the optimal placement of detectors. The process to continue until the stopping condition fails, which may be one of the following:

1. $\left|F^k(w) - F^{k-1}(w)\right| < \varepsilon$, where $\varepsilon > 0$ – a small predefined number.

2. $\sum_{i=1}^{20} \min_j \left[(x_1^{ik} - x_1^{jk-1})^2 + (x_2^{ik} - x_2^{jk-1})^2 \right] < \delta,$ where $\delta > 0$ – a small predefined number.

3. $\exists k : F^k(w) > F^{k-1}(w)$.

The above conditions indicate that the process of finding the optimal placement is completed, since the value of objective function at different stages are not significantly different, or placing the same sensor at different iterations, or worse objective function.

The proposed method is not only to solve this problem under no differential, polls extreme and objective function. In addition, the drawback of the method is the need to encode in different number systems that are too time-consuming process.

Using the objective function (2) is not always adequate. In ideal conditions, each point belongs to the space area of at least one detector. In practice, this condition is not always done. To target function did not lose its meaning, as in this case, the denominator is zero, we introduce the term, which means meaningful penalty part. Target function will take this form:

$$F(w)=\sum_{i=1}^{10}\chi\Big(\big(\sum_{j=1}^{20}\chi(d_{ij}<r)\big)>0\Big)\cdot\frac{1}{1-(1-p)^{\sum_{j=1}^{20}\chi(d_{ij}<r)}}\cdot\min_j d_{ij}+$$
$$+\sum_{i=1}^{10}\chi\Big(\big(\sum_{j=1}^{20}\chi(d_{ij}<r)\big)=0\Big)\cdot\min_j d_{ij}. \quad (3)$$

The first term in (1) meet when a point of fire is the area of responsibility at least one detector, the second term is the penalty and the objective function value will increase if this point does not belong to any area of responsibility.

A series of experiments that demonstrated the effectiveness of the proposed methods. The first experiment was devoted to the study of the dynamics of the target function. Fig. 2 and 3 show how changing its value depending on the number of detectors and their level of reliability.

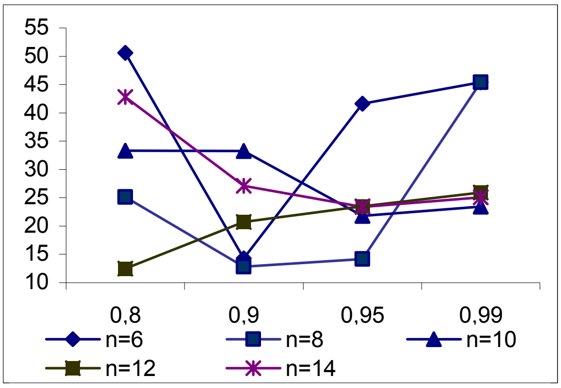

Fig. 2. Dynamics of the objective function for different numbers of detectors

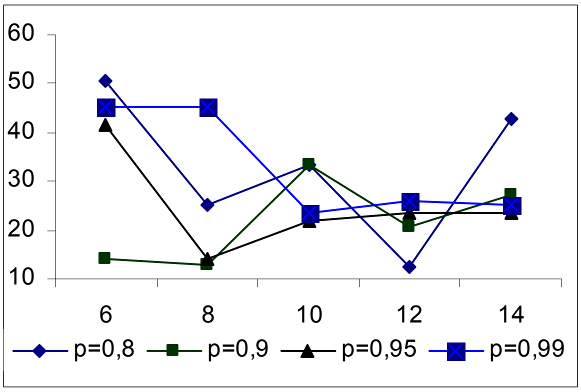

Fig. 3. Dynamics of the objective function for different values of the reliability of detectors

The results of other experiments indicate a relatively equal accuracy using the methods based on evolutionary strategies and genetic algorithms. These minor differences with classical triangular and rectangular schemes explained uniform fire load space. If the number of detectors is inadequate or excessive, the results of the proposed methods are more effective. Proposed methods of rational use in the case of low reliability of detectors or detectors of differences that get installed in the standard. The proposed objective function is not the only one.

An important task is a "generalizing" the objective function (3) for a more general case, which includes:

- Availability of high-risk;
- Uneven permanent fire load;
- Alternating irregular fire load.
- Consider one of these cases.

In the room with the uniform fire load is a source of increased danger. In this case, it is important to consider the priority placement of fire detectors closer to these sources, while trying not to leave without protection of other areas of the room. We write the target function as follows

$$F(w)=\alpha\cdot\sum_{i=1}^{M}\chi(\sum_{j=1}^{N}\chi(d_{ij}<r)>0)\cdot\frac{1}{1-(1-p)^{\sum_{j=1}^{N}\chi(d_{ij}<r)}}\cdot\min_{j}d_{ij}+$$
$$+\beta\cdot\sum_{k=1}^{K}\chi(\sum_{j=1}^{N}\chi(d_{kj}<r)=0)\cdot\frac{1}{1-(1-p)^{\sum_{j=1}^{N}\chi(d_{kj}<r)}}\cdot\min_{j}d_{kj}+ \quad (4)$$
$$+\gamma\cdot\sum_{i=1}^{M}\chi(\sum_{j=1}^{M}\chi(d_{ij}<r)=0)\cdot\min_{j}d_{ij}+\delta\cdot\sum_{k=1}^{K}\chi(\sum_{j=1}^{M}\chi(d_{kj}<r)=0)\cdot\min_{j}d_{kj},$$

where K - number of sources of increased danger, $\alpha,\beta,\gamma,\delta$ - weights corresponding fragments of the target function. The first term of objective function indicates the minimum time of operation of the detectors from the point of fire and the magnitude, the inverse reliability of alarm system. The second term is similar to the first, but had to fire that caused the source of increased danger. The third and fourth terms (4) is a penalty function in case of fire or point source of increased danger is not in the area of responsibility of a single detector.

Odds α,β,γ and δ included in (4), easily found using the method of analysis of hierarchies T. Saaty [6]. To find the minimum (4) applied genetic algorithm and evolutionary strategy [4]. The difference from the previously considered case is that it is necessary to form another matrix of distances $D^K=\left\{d_{kj}\mid k=\overline{1,K},j=\overline{1,N}\right\}$, whose elements are the distances from the k source of fire hazard to the j detector. Note that in our problem such sources are stationary. Potential solutions are the coordinates of the points placing detectors (fixed number of them), and point of fire have uniform distribution in the region Ξ.

These models are designed for areas with uneven and variable fire load and proposed evolutionary method for determining the optimal structure fire detectors [7], the task is to optimize the structure of fire detectors is to find

$$\min_{w}F(w),$$

where $w=(x_d^1,y_d^1,x_d^2,y_d^2,...,x_d^N,y_d^N)$ - the location coordinates of the points of fire detectors.

Conclusion

The problem of optimizing the structure of the fire monitoring, part of which is a fire alarm system is extremely important given the dynamics of those killed and injured in fires, as well as the current shortage of resources and finance. Designed target the answers to practical cases with the presence of buildings and structures sources of increased danger and irregular fire load space. Given the nature of the dependencies obtained, the proposed optimization objective functions make based on evolutionary methods. The peculiarity of the developed technology is the use of expert opinions and relevant methods of analysis. The result of its implementation are the coordinates placement of fire detectors that will improve the reliability of fire alarm system and minimize the time of its operation in case of fire.

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