УДК 614.8

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IMPACT MODEL OF HAZARD EMERGENCY SITUATION ON THE TESTIMONY OF A THERMAL IMAGER

The analysis of statistical data on the effectiveness of the emergency response units is conducted, it is obtained the distribution functions of time of arrival, localization and liquidation of fires. The correlation between the mean and standard deviation dates in random variables is established. The mathematical model of the impact of hazards emergency and the type of material on the walls of the thermal imager is obtained.

Keywords: Emergency situation, thermal imager, emissivity, probability, time, temperature.

Problem formulation. One variety of technogenic emergencies are fires. Nowadays during fire extinguishing and sizing up, the visual method (in the visible range) is used for the definition of flame or smoke. However, in some cases, for example, at the initial stage or in the development of fire the source can be determined on the basis of the wavelengths that are invisible to a human eye, with the help of the thermal imager.

Considering all the benefits of thermal imaging, today one of the problems is the lack of methods for the application of these devices as well as the recommendations to the tactical actions, mathematical apparatus for emergency situation technogenic characters assay based on images in the infrared range, etc.

Analysis of recent research and publications. In [1-4] domestic and foreign experience of thermal application in fire-fighting is studied. It was found that there is no recommendations for tactical action based on the analysis of the infrared images both while fighting fire and during sizing it up.

In [3] it was evaluated the temperature of external wall surface of the building, room. The features of temperature changes by varying the values of the wind speed, the thermal characteristics of the walls and the room temperatureare considered.It was analyzed the dependence of the surface temperature of the walls of the building from the wind speed at different values of $T_1$and the characteristics of the wall.

Analysis of the figure shows that the outer wall temperature changes substantially at wind speeds less than 5 m/s. Also at high wind speeds (higher than 10 m/s) a temperature difference disappears almost completely when the T1 of wall and thermal characteristics of the wall are changing. Thus, if the room is fully exposed to high temperatures, it is difficult to determine a temperature from the outer surface of the wall.

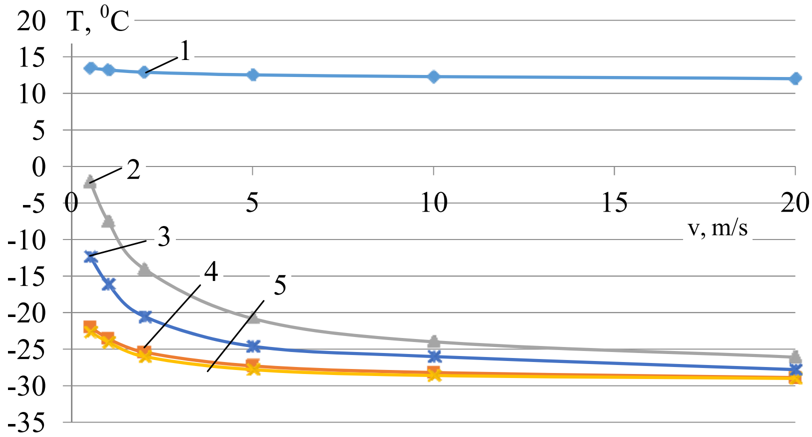

Fig. 1. Dependence of the surface temperature of the building walls from the wind speed: 1 – T_{1s}; 2 – T_{2s} (T_1=150 °C); 3 – T_{2s} (T_1=400 °C+10 cminsulation); 4 – T_{2s} (T_1=150 °C+10 cm insulation); 5 – T_{2s}

At the same time, when using the thermal imagers we should consider the characteristics of material, in which limits the temperature measurement is made, the flux from other objects. The output electrical signal is proportional to the total thermal infrared absorption of the flux: $U \sim \Phi_{tot}$. Full flux comprises three components: flux of an object of termographing itself, flux from the other (surrounding) objects reflected from the object and flux generated by the atmosphere [5, 6]

$$\Phi_{tot} = \varepsilon_{ob}\tau_{atm}\Phi_{ob} + (1-\varepsilon_{ob})\tau_{atm}\Phi_{amb} + (1-\tau_{atm})\Phi_{atm}, \quad (1)$$

where ε_{ob} – quotient of emissivity of the object; τ_{atm} – quotient of transmittance through the atmosphere; Φ_{ob} – own flux from the object; Φ_{amb} – flux from other objects; Φ_{atm} – flux generated by atmosphere.

When determining the temperature at less than 30-50 m absorption in atmosphere can be neglected, i.e. τ_{atm} =1, then equation (1) can be written

$$\Phi_{tot} = \varepsilon_{ob}\Phi_{ob} + (1-\varepsilon_{ob})\Phi_{amb}. \quad (2)$$

Heat flow in any spectral range can be expressed as follows through the temperature

$$\Phi = \int_{\lambda_1}^{\lambda_2} R_\lambda(T)d\lambda = T^n, \quad (3)$$

where n – parameter depending on the wavelength. Then the equation (2) can be written as

$$T_{ap}^n = \varepsilon T^n + (1-\varepsilon)T_{amb}^n. \quad (4)$$

where T_{ap} –radiation temperature.

In [3] for the stationary mode it is obtained a system of equations for determining the wall temperature and emissivity

$$\begin{cases} q_1 = \alpha_2 \cdot (T_{2s} - T_2); q_2 = \alpha_1 \cdot (T_1 - T_{1s}); \\ q_3 = \left[\sum_{i=1}^{n} \left(\frac{\delta_i}{\lambda_i} \right) \right]^{-1} \cdot (T_{1s} - T_{2s}); \\ q_1 = q_2 = q_3 = const; \alpha_1 = 1,66 \Delta T^{1/3}; \\ \alpha_2 = 5,07 v^{0,656} + 3,25 e^{-1,91v}; \\ \lambda = \frac{0,002899}{T_{2s}}; r(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda k T_{2s}}} - 1}, \end{cases} \quad (5)$$

where λ – wavelength; c – light speed; k – Boltzmann constant; h –Planck constant; v – wind speed; T_{1s}, T_{2s} – temperature of the inner and outer wall surfaces; α_1, α_2 – heat transfer coefficient at the inner and outer wall surfaces.

In addition, analysis of documents concerning the procedure for the application of thermal imagers have showed the absence of methods for their application, tactical recommendations to the actions, and the mathematical apparatus for fire analysis based on images in the infrared range, etc. For example, in [7] only once the word "imager" is mentioned, namely in Sec. 4.6.5:

"Depending on the availability of forces and means the searching work is carried out on the basis and with the use of:

- • eyewitness records;
- • visual indication (from the remains of clothes and things on the surface of the stabilized layer);
- • readings from searching devices (gas analyzers, probes, magnetometer, **thermal imagers**, acoustic systems);
- dogs».

Statement of the problem and its solution. The aim is to build a model of exposure of emergency hazards (for example, fire) and the type of material on the walls of the thermal imager readings.

To assess the influence of the emissivity on temperature of gray bodies, without radiation of the surrounding objects, it is permissible to use dependence [5, 6]

$$\frac{\Delta T}{T} = \frac{1}{4} \frac{\Delta \varepsilon}{\varepsilon}. \quad (6)$$

Emissivities of building materials, bywhich in most cases the temperature is determined can be represented as tab. 1.

Tab. 1. Emissivity value

Identification of the substance	Emission coefficient
Aluminum	0,04-0,19
White plaster	0,88
Stucco	0,90
Sheet steel	0,50-0,60
Oil gray gloss paint	0,96
Oil gray matte paint	0,97
Oily black gloss paint	0,92
Oily black matte paint	0,94
Matt lacquer	0,93
Facing brick red	0,92
Galvanized sheet iron	0,23-0,28
Gray plaster	0,92

Analysis of the expression (6) leads to the conclusion that the error in determining the temperature without knowing the type of material may make more than 10 °C.

At the same time, when defining the temperature the time of the fire is of great importance, as it affects the temperature of the room, and, respectively, heating the wall of the building. In order to determine the time of the fir the analysis of the actual time of arrival of the fire departments was conducted. Based on analysis of more than 50000 fires [8], it was found that the random variable time until the arrival, localization and liquidation can be described by Rayleigh distribution

$$f(x) = \begin{cases} \frac{x}{\sigma^2} \cdot \exp\left(-\frac{x^2}{2 \cdot \sigma^2} \right), & x \geq 0; \\ 0, & x < 0. \end{cases} \qquad (7)$$

The values of the expectation and variance for the three random variables are presented in tab. 2.

Tab. 2. The parameters of random variables

Arrival time (τ_{pr})		Time of localization (τ_{lok})		Time of liquidation (τ_{lik})	
μ_{pr}	σ^2_{pr}	μ_{lok}	σ^2_{lok}	μ_{lik}	σ^2_{lik}
28,13	1015,9	47,04	2183	75,9	5001

For Rayleigh σ distribution is determined from the expression

$$\mu = \sigma\sqrt{\frac{\pi}{2}}, \qquad (8)$$

then the expression (1) for τ_{pr} and τ_{lok} and τ_{lik} taking into account (7) can be written as

$$f(\tau_i) = \frac{\pi\tau}{2\mu_i^2}\cdot\exp\left(-\frac{\tau^2\pi}{\mu_i^2}\right), \quad \tau\in[0;+\infty). \qquad (9)$$

Distribution function and probability density for τ_{pr}, τ_{lok} and τ_{lik} according to (9) are shown in the Fig. 2.

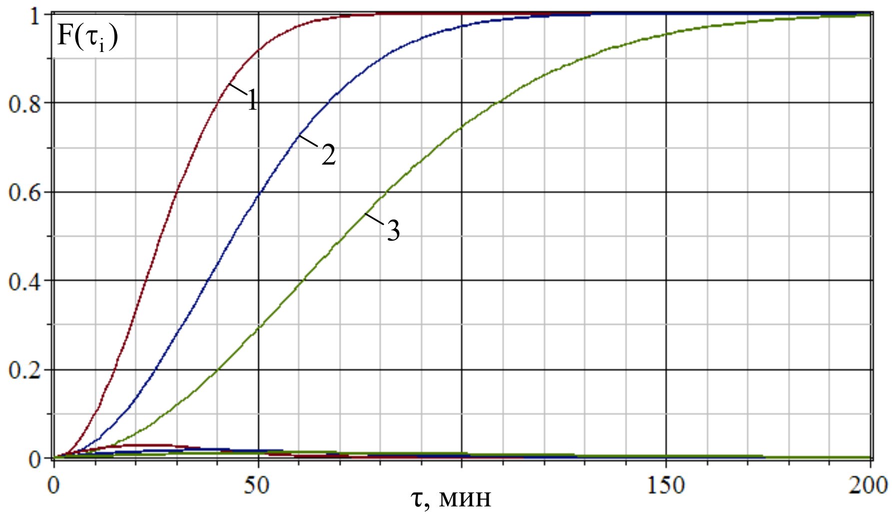

Fig. 2. The distribution function: 1 - the time of arrival of the fire departments; 2 - Time of localization; 3 - time of liquidation

Also it has been found that σ_i varies proportionally to μ_i (Fig. 3). This suggests that the random variable of execution time for some operation during the emergency response has its own nature of change, which is subject to the following relationship

$$\sigma_i = 0{,}914\mu_i + 8{,}747, \quad \mu_i\in[28{,}13;75{,}9]. \qquad (10)$$

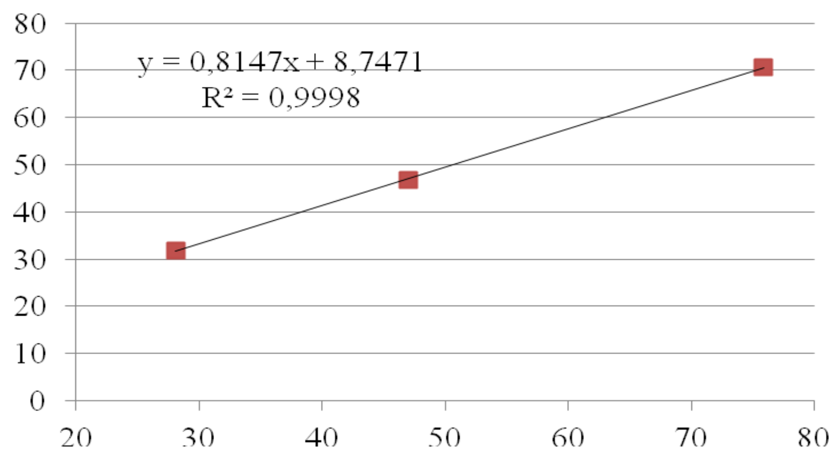

Fig. 3. The dependence of the standard deviation from the expectation

In case of fire, there is a change in temperature inside the room, which entails a change in the parameters of the wall according to the expression

$$\frac{\partial}{\partial \tau} T(x, \tau) = a_{st} \cdot \frac{\partial^2}{\partial x^2} T(x, \tau), \qquad (11)$$

where a_{st} – thermal diffusivity of the wall; $T(x, \tau)$ – temperature at the distance x from the inner side walls at time τ.

To construct a mathematical model we take the boundary conditions of the third kind on the outside and on the inside surface of the wall

$$\lambda_{st1} \frac{\partial}{\partial x} T(x, \tau)\Big|_{x=x_1} = \alpha_1 \left(T_1 - T_{pom}\right); \quad \lambda_{st2} \frac{\partial}{\partial x} T(x, \tau)\Big|_{x=x_2} = \alpha_2 \left(T_{vs} - T_2\right); \qquad (12)$$

Given the initial conditions

$$T(x, 0) = T_0, \qquad (13)$$

and the dependence of the temperature at the standard temperature range of fire, a mathematical model of the impact of emergencyhazards and the type of material on the walls on the thermal imager readings can be written as

$$\begin{cases} \frac{\partial}{\partial \tau} T(x, \tau) = a_{st} \cdot \frac{\partial^2}{\partial x^2} T(x, \tau); \\ \lambda_{st1} \frac{\partial}{\partial x} T(x, \tau)\Big|_{x=x_1} = 1{,}66 \Delta T^{1/3} \left(T_1 - T_{pom}\right); \\ \lambda_{st2} \frac{\partial}{\partial x} T(x, \tau)\Big|_{x=x_2} = \left(5{,}07 v^{0,656} + 3{,}25 e^{-1,91v}\right)\left(T_{vs} - T_2\right); \\ T(x, 0) = T_0; T_{pom} = 345 \cdot \lg\left(8 \cdot \tau + 1\right) + T_0; \\ f(\tau_i) = \frac{\pi \tau}{2\mu_i^2} \cdot \exp\left(-\frac{\tau^2 \pi}{\mu_i^2}\right), \quad \tau \in [0; +\infty); \\ \lambda = \frac{0{,}002899}{T_{vs}}; r(\lambda, T) = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda k T_{vs}}} - 1}; \frac{\Delta T}{T_2} = \frac{1}{4} \frac{\Delta \varepsilon}{\varepsilon}. \end{cases} \qquad (14)$$

Conclusions. As a result of the work the statistical data on effectiveness of the emergency response units are processed and it is obtained the distribution function of time of arrival, localization and liquidation of fires. Correlation between the mean and standard deviation of the mediumrandom variables is established. The mathematical model of the impact of emergency hazards and the type of material on the walls on the thermal imager readings is obtained.

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Ю.П. Ключка, Н.В. Кринська, Х. Ш. Гасанов

Модель впливу небезпечних факторів надзвичайної ситуації на покази тепловізора

Проведено аналіз статистичних даних по результативності роботи аварійно-рятувальних підрозділів, отримані функції розподілу часу прибуття, локалізації та ліквідації надзвичайної ситуації (пожежі). Встановлено кореляційний зв'язок між математичним очікуванням і середньоквадратичним відхиленням цих випадкових величин. Отримана математична модель впливу небезпечних факторів надзвичайної ситуації і типу матеріалу стін на покази тепловізора.

Ключові слова: надзвичайна ситуація, тепловізор, коефіцієнт випромінювання, імовірність, час, температура.

Ю.П. Ключка, Н.В. Крынская, Х. Ш. Гасанов

Модель воздействия опасных факторов чрезвычайной ситуации на показания тепловизора

Проведен анализ статистических данных по результативности работы аварийно-спасательных подразделений, получены функции распределения времени прибытия, локализации и ликвидации ЧС техногенного характера (пожара). Установлена корреляционная связь между математическим ожиданием и среднеквадратичным отклонением даных случайных величин. Получена математическая модель воздействия опасных факторов чрезвычайной ситуации и типа материала стен на показания тепловизора.

Ключевые слова: чрезвычайная ситуация, тепловизор, коэффициент излучения, вероятность, время, температура.