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DETECTING FIRE IN EARLY STAGE - A NEW APPROACH

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Abstract. *The field of fire science has made great strides in the past two decades in accordance with technology development. However, there is general agreement that the greatest shortcoming of fire detectors is a high rate of false alarms that limit their credibility with the public. Various methods have evolved to solve this problem. This paper presents a new approach for increasing reliability and accuracy of alarm decision in fire detection system.*

1. INTRODUCTION AND BACKGROUND

In recent years fire sensors have evolved from threshold devices to multi-mode, multi-criteria sensors that can employ decision about alarm. Even if on that way reliability of system was advanced, number of false alarms is still considerable. The reasons of arising false alarm in fire protection system may be different. There are several types of false alarms: fault signal as a false alarm caused by a component failure or other kind of technical failure, spurious alarm caused by adequate phenomenon (properly detected) but there is not hazardous situation (e.g. smoke in kitchen), deceptive alarm caused by non-hazardous phenomenon which is interpreted as a dangerous phenomenon (e.g. dust, insect etc.), system false alarm caused by software malfunction or operator error and deliberate alarm caused by human intent (e.g. smoke from cigarette or signal from a manual call point).

Aim of every system is detection of fire in its early stage, by means of discovering tendency of signal developing. On the basis of sensor data it is possible to predict developing of fire signal. The mathematical models for the compartment fires in the buildings were various developed in the response of the purpose of utilizations. New fire detection concepts and algorithms are justified only if they improve existing ones with lower false alarm rates and greater sensitivity to starting fires.

No matter what procedure is used for processing the signal in fire detection systems, the major characteristic of most assigned algorithms is treatment of alarm as a fixed value. The decision making based on threshold value means that this decision is based on preset (defined by standard) value. This conventional logic practically leads to a discrete function

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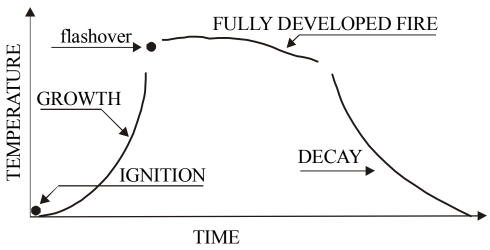

Fig. 1. Fire phases

which from the given set of data gives one predicted output value. In this paper, we proposed the new function for describing the front edge of fire signal and its modification for predicting fire in early stage, independently of threshold value.

An idealized compartment fire has three, distinct phases: growth phase, steady-burning phase, and decay phase shown on fig. 1.:

The primary importance of the appropriate selection of the design fire's growth is in obtaining a realistic prediction of detector and sprinkler activation, time to start evacuation, and time to initial exposure of occupants. Thus, this is the most important to an egress analysis which makes up the majority of alternate design analysis.

Along with selecting an appropriate mathematical model for growth phase, choosing a relevant set of design fires with which to challenge the design is crucial to conducting a valid analysis.

On the occasion of modeling fire growth phase, of particular interest is the heat release rate (HRR) parameter, since it is driving force for most other phenomena in fire. However, HRR curves and corresponding temperature curves a little differ in part of growth phase, immediately after ignition, as shown on figure 2. [6]:

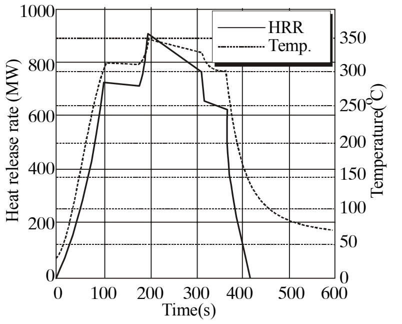

Fig 2.a) HRR curve vs. temperature curve (fuel: diesel)

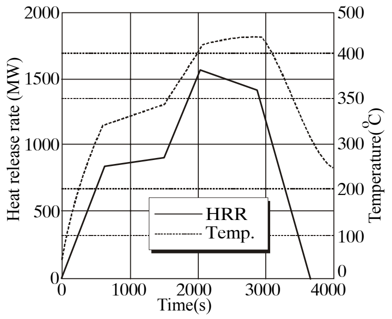

Fig 2.b) HRR curve vs. temperature curve (fuel: wood)

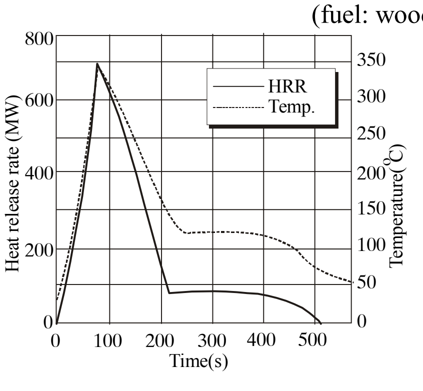

Fig 2.c) HRR curve vs. temperature curve (fuel: polyurethane)

On the other hand, the reasons for using of temperature in modeling fire growth phase rather than HRR are as follows:

– high temperatures are a characteristic of combustion;
– high temperatures can generate large radiative fluxes which support fires (e.g. pyrolysis or vaporization of fuels, flame spread, flashover);
– temperature is an indicator of the potential damage;
– temperature is direct indicator of heat release rate;
– temperature is one of the easier to measure fire characteristics.

2. THE GROWTH PHASE OF FIRE DEVELOPMENT

Generalization of the interpretation of signals from temperature sensors after ignition is very complicated because of including many parameters like open doors or windows, vent flows and similar. However, the most fire curves are similar in their growth phases, independently of fuel type. On the following figures, fire curves for different kind of fuels and for different quantity of the same fuel are shown.

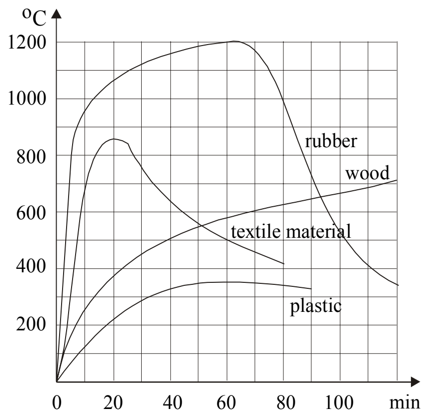

Fig. 3. Fire curves for different types of fuel

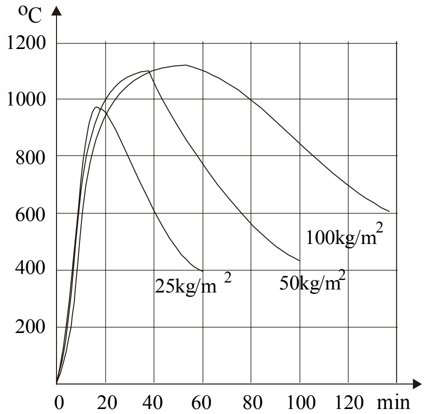

Fig. 4. Fire curves for different quantities the same fuel

In the most cases the front edge of fire signal may be consider to be a reliable confirmation about fire growth. From the previous figures is obvious that growth phase of fire may be treated like pulse phenomena. This means that is possible approximation of fire growth phase with Heaviside function, with linear combination of exponential functions or with some suitable function which satisfactory describes front edge of pulse phenomena.

For approximation of fire growth phase we propose, as very simple and accurate, function as follows [1]:

$$t = a\left[\frac{\tau}{b}e^{1-\frac{\tau}{b}}\right]^{c} \tag{1}$$

where: t - temperature, τ - time, a, b, c - unknown coefficients, with meanings as follows:

$a = t_{\max}$ - Maximal temperature, $b = \tau_{\max}$ - Time instance for maximal temperature, c - rate of rise of function.

In order to prove a properly choice of function (1), it's made numerical experiments on the several sets of experimental data. Experiment is carried out in this way: function (1) that has unknown coefficient c adjusts on accurate value in saddle point (τ_1, t_1) [1]:

$$c = \frac{\ln\left(\frac{t_1}{t_{max}}\right)}{\ln\frac{\tau_1}{\tau_{max}} + 1 - \frac{\tau_1}{\tau_{max}}} \tag{2}$$

Two characteristic shapes of fire curve and corresponding approximation with function (1) are shown on figure 5. The curve on the left side of figure has shape like pulse phenomena (fuel: polyurethane thin table), thus it is convenient for approximation. The curve on the right side is very similar to idealized standard fire curve (fuel: diesel).

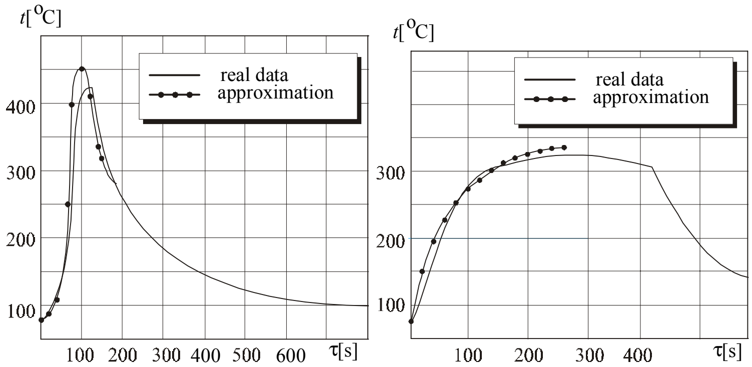

Fig. 5. Approximation of fire growth phase

Table 1. presents the real data and data from approximation. The coefficients obtained by (2) are c = 6.91 and c = 0.79 for the left and the right approximation function on figure 5, respectively.

Table 1. Real data and data obtained with approximation fire growth phase

Time	Real data	Approx. (left)	Time	Real data	Approx. (right)
τ(s)	T [°C]	T [°C]	τ (s)	T [°C]	T [°C]
0	25.00	25.00	0	25.00	25.00
20	35.00	26.41	20	70.00	101.75
40	70.00	67.69	40	120.00	145.00
60	150.00	201.65	60	165.00	177.50
80	350.00	348.83	80	200.00	203.04
100	380.00	405.00	100	230.00	223.42
120	370.00	361.29	120	245.00	239.72
140	270.00	269.96	140	255.00	252.69
		-------	160	260.00	262.88
		-------	180	265.00	270.73
		-------	200	268.00	276.58
		-------	220	270.00	280.70
		-------	240	273.00	283.35
		-------	260	275.00	284.71

The results of numerical experiments show that the function (1) satisfactory describes fire growth phase before flashover, and can be used for approximation for most fires except smoldering ones. However, previous method is global and therefore can be useful in reconstruction of fire. It is necessary to know all data before approximation and consequently this method may not be used in real time, during the fire data acquisition. Unfortunately, when all of data are known, the fire is fully developed, and no prediction has any sense. Thus, it is necessary to modify the function (1) to obtain the function which can be used in real time.

3. APPROXIMATION OF FIRST EDGE OF FIRE SIGNAL

The function described in previous chapter is unusable in real time detection from two reasons: the first, errors of approximation with function (1) are the biggest immediately after ignition, in part of curve where is necessary to make decision about alarm, and the second, on the basis of minimal set of acquired data we have to predict the fire growth and time instance of alarm.

Simplification of function (1) is done such a way coefficient $c = 1$, as follows:

$$t = a\left[\frac{\tau}{b}e^{1-\frac{\tau}{b}}\right] \tag{3}$$

With this simplification the obtained function has no saddle part, e.g. function starts with alarm slope, as shown on figure 6.

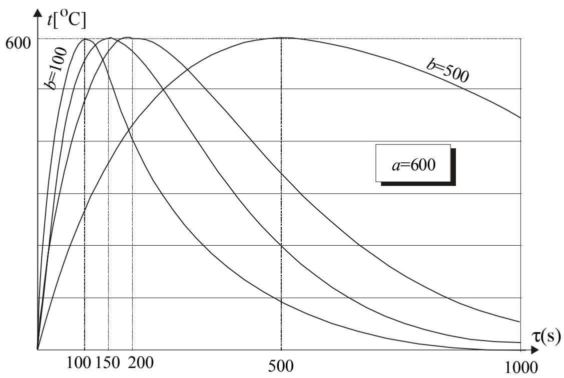

Fig. 6. Function for approximation of first edge

The prediction of fire alarm has to be stated on the arbitrary set of previous, acquired data, as less as possible. If we choose to view the set of data in the time window the length of which is constant, consequently we use the known time sliding window principle [3,2]. Measuring of time in every time sliding window begins from relative time one, and value on ordinate is offset of temperature related to value on the beginning left side of window. This procedure is shown on next figure.

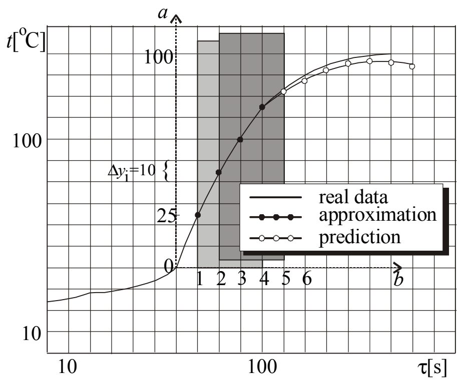

Fig. 7. Time sliding window principle

For numerical experiment with new function in real time, using time sliding window principle, it's investigated set of experimental data shown on the right side on figure 5., which is most similar to idealized fire curve. The aim ware to compare data obtained with approximation in sliding window with data obtained with function (1) previously shown in Table1. Data for applying least squares method are shown in table 2. The results of approximation of the first edge of fire signal in two adjacent time sliding windows are shown in figure 8. and table 3.

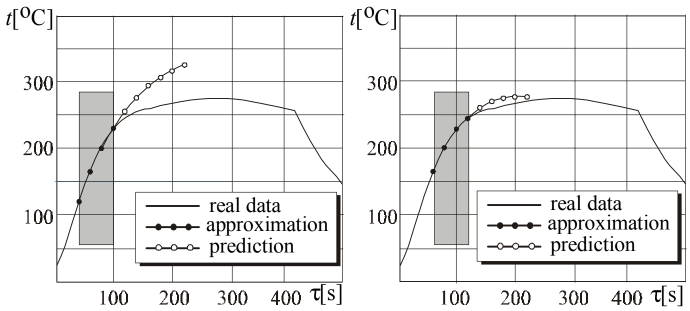

Fig. 8. Two successive approximation in time sliding window

Table 2. Real data and data for approximation (defined by offset)

Time τ[s]	Real data T[°C]	n	Data for approx. window 1 T[°C]	n	Data for approx. window 2 T[°C]
20	70.00				
40	120.00	1	50.00		
60	165.00	2	95.00	1	45.00
80	200.00	3	130.00	2	80.00
100	230.00	4	160.00	3	110.00
120	245.00			4	125.00

Table 3. Real data and data obtained with approximation of the first edge of fire signal

Time τ [s]	n	App.- window 1 T[°C]	App. - window 2 T[°C]	Real data T[°C]
40	1	50.49+70=120.49		120.00
60	2	93.58+70=163.58	45.24+120=165.58	165.00
80	3	130.08+70=200.08	80.40+120=200.80	200.00
100	4	160.73+70=230.73	107.17+120=227.17	230.00
120	5	186.19+70=**256.19**	126.98+120=246.98	245.00
140	6	207.05+70=**277.05**	141.04+120=**261.04**	255.00
160	7	223.85+70=**293.85**	150.40+120=**270.40**	260.00
180	8	237.08+70=**307.08**	155.92+120=**275.92**	265.00
200	9	247.16+70=**317.16**	158.35+120=**278.35**	268.00
220	10	254.50+70=**324.50**	158.30+120=**278.30**	**270.00**

As an example, in order to prove efficiency of proposed function, the set of data in developed phase of fire was chosen, because of this function is quite adequate under room temperatures. The shadowed cells in table contain the predicted data.

Obviously, with every "sliding" of time window, the prediction is better and better. For example, results of approximation in the first time sliding window show that during 10 time ticks (period of acquiring fire data) temperature will be 324.50 ºC, in the second window value of maximal temperature is 278.30 ºC, which is little difference from real data. Each new approximation in successive time sliding window will produce value of temperature peek closer to real data.

4. CONCLUSION

In this paper the new function for approximation of front edge of the signal in early stage of fire development is presented. With this function, it is possible very fast, immediately after ignition, to predict the temperature development during the fire growth phase, its maximal value and the time interval needed to achieve this value. This function provides significantly better results in order to the already known curves which describes the fire growth phase, for example ISO standard temperature curve. With this function, it is possible to open new approach in fire signal processing and interpretation in early stage.

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OTKRIVANJE POŽARA U RANOJ FAZI - NOVI PRISTUP

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Veliki napredak koji je ostvaren u naučnoj oblasti zaštite od požara u poslednje dve decenije odvijao se u skladu sa razvojem tehnologije. Međutim, opšte je prihvaćeno mišljenje da dojava lažnih alarma, kao najveći nedostatak javljača požara, ograničava pouzdanost i umanjuje poverenje javnosti u sisteme za dojavu požara. Tokom razvoja sistema za dojavu korišćeni su razni metodi da bi se prevazišao ovaj problem. U ovom radu je prikazan novi pristup prevazilaženja problema dojave lažnih alarma koji povećava pouzdanost i tačnost donošenja odluke o alarmu u sistemima za otkrivanje i dojavu požara.