

Simulation of the PIR detector active function

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Abstract. The work deals with the behaviour of the PIR detector in an environment with great influence of a thermal background. It was necessary to perform simulations of the thermal behaviour of the sensor by COMSOL Multiphysics in different modes of heating the room to be able to prove that the PIR detector can function as an active detector with improved detection possibilities of intruders who would be invisible to a detector under normal circumstances. This confirms the detector's ability to work on the principle of active detector, i.e. as transmitter and receiver of thermal radiation and evaluation of heat flux changes depending on the type of the heater and the shrouding.

1 Introduction

This paper deals with the function of the passive PIR detector that can function as an active detector under certain conditions, which enhance its possibilities in terms for detecting intruders, who could successfully mask under normal circumstances and they would become invisible for the detector.

2 Principle of the PIR detector

The principle of the PIR detector is shown in Fig. 1. The detector consists of pyroelement 1 which is receiving radiation from an intruder. This radiation passes through the filter 2, which suppresses radiation of wavelength less than 8 micron and greater than 12 micron and is therefore permeable for the 8 to 12 microns with a maximum of 10 microns wavelength, which corresponds to the temperature of the intruder, i.e. about 37 ° C. Infrared optics detector 3 performs the concentration of thermal radiation on pyroelement while creating segments 4, wherein the detector "see" and "not see". If intruder moves tangentially 5 over these areas, this leads to intermittent radiation after passing through the filter to generate pyroelement charge whose magnitude is measured after signal processing 6 and then the signal is sent as an alarm message on I&HAS security system.

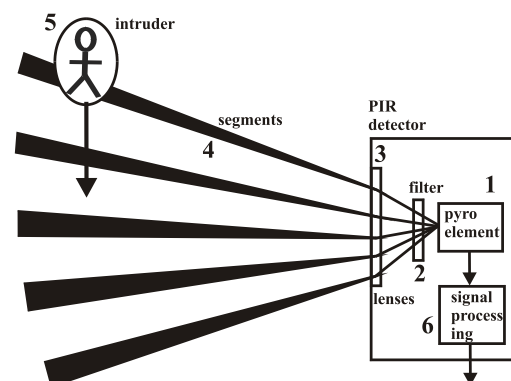


Figure 1. Principle of PIR detector.

3 Principle of active function of the PIR detector

The main function of the PIR detector is relatively easy to disrupt such a way that object (intruder) does not transmit thermal radiation. This can be relatively easily realized as an intruder uses curtain that hides the intruder in the direction of the PIR detector. In Fig. 2 are shown infrared images of various materials for the intruder masking. On left side is a man dressed in neoprene, in middle in winter clothes and on the right man disguised in an insulated liner.

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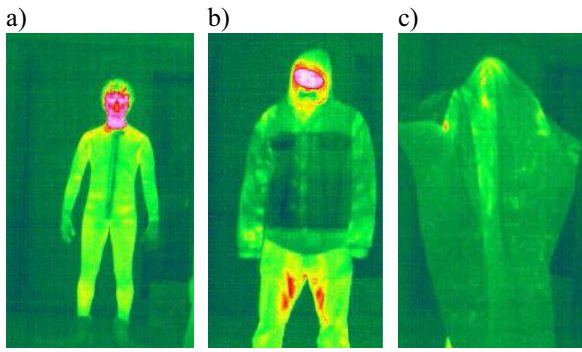


Figure 2. Masked intruder dressed in a) neoprene, b) winter clothing, c) isothermal foil.

Fig. 3 shows the principle of active PIR detector. A source of thermal radiation is in the background. It transmits radiation in the range of 10 μm wavelength. If the masked intruder moves in front of this background, there is a change of the heat flux from the background so that it obscures the individual segments, which quality PIR detector measures as a change of the incident radiation and activates the alarm condition.

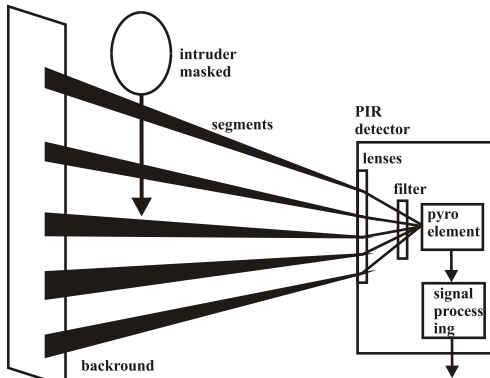


Figure 3. Principle of active PIR detector

4 Mathematical model of heating sensor by radiation

Thermal radiation incident on the sensor is partially reflected and partially absorbed by the sensor, thereby to ensure that the temperature measured at the beginning of the measurement does not fully effective temperature.

We used the Stefan-Boltzmann law for the quantitative description of the temperature distribution in the pyroelement inside the detector, which is heated by radiation. According to Stefan-Boltzmann law, the density of heat flux between the source and the heated surface is expressed as (1) [3]:

$$q(\tau) = \sigma.C(T_2^4 - T_1^4) \quad (1)$$

where:

σ - Stefan-Boltzmann constant, $\sigma = 5.67.10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
 C - constant which characterizes emission surface and geometric properties, [1]

T_2 - source temperature, [K]

T_1 - temperature of heated surface, in this case the surface temperature, [K] .

Mathematical model of the sensor (pyroelement) heating can be described by equations (2) – (5):

$$\frac{\partial T}{\partial \tau} = a. \frac{\partial^2 T}{\partial x^2}, \quad (0 \leq x \leq b, 0 < \tau) \quad (2)$$

$$\left(\frac{\partial T}{\partial x} \right)_{x=0} = 0 \quad (3)$$

$$\lambda \left(\frac{\partial T}{\partial x} \right)_{x=b} = q \quad (4)$$

$$T = T_p \text{ for } \tau = 0 \quad (5)$$

where:

b - half thickness of the sensor, [m]

x - direction coordinate, [m].

Analytical solution of non-stationary temperature field for sensor plate shape symmetrically heated by radiation has been obtained by Laplace transform as:

$$\frac{T - T_p}{T_c - T_p} = K_i \left[Fo + \frac{1}{2} \left(\frac{x}{b} \right)^2 - \frac{1}{6} - 2 \sum_{n=1}^{\infty} \frac{\cos \left(\frac{x}{b} p_n \right)}{p_n^2 \cos(p_n)} e^{(-Fop_n^2)} \right] \quad (6)$$

where K_i is Kirpičev criterion (7)

$$K_i = \frac{qb}{\lambda(T_c - T_p)} \quad (7)$$

T_c is medium temperature of radiators.

Fourier criterion Fo represents the dimensionless heating time which can be calculated according to equation:

$$Fo = \frac{a\tau}{b^2} \quad (8)$$

where:

τ - time of heating, [s]

a - thermal diffusivity of sensor, $[\text{m}^2.\text{s}^{-1}]$

The thermal diffusivity is given by equation:

$$a = \frac{\lambda}{\rho c_p} \quad (9)$$

where:

λ - the thermal conductivity of sensor, [$\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$]

ρ - the density of the sensor material, [$\text{kg}\cdot\text{m}^{-3}$]

c_p - the specific heat capacity of the sensor material, [$\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$].

Members p of the analytical solution of (6) are determined from equation (10):

$$p_n = n \cdot \pi \quad (10)$$

According to the solution (6) it is evident that with increasing time of heating, the influence of endless series elements decreases, i.e., we can also expect Fourier criterion Fo for which influence endless series may be neglected and for $Fo > Fo_k$ the temperature at any point in the wall is almost linear function of time and temperature profile across the pyroelement (in x -axis direction).

5 Simulations in Comsol Multiphysics

The aim of simulations was to compare the incident heat radiation to the surface of pyroelement, if the intruder was in the room, or not. It was considered both heated and unheated room with vertical or floor heater.

Fig. 4 shows room with an unheated vertical heating. Fig. 4a depicts the layout position of the heater, pyroelement and intruder. Fig. 4b shows the distribution of incident heat flux to the surface pyroelement and in Fig. 4c is seen course of the heat flux in vertical section of the pyroelement.

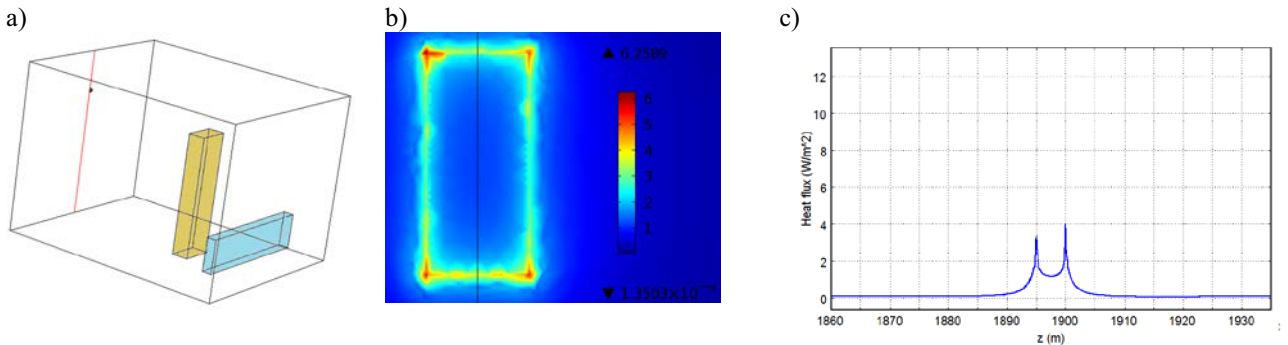
Fig. 5 shows the same situation as in Fig. 4 for the heated room.

Fig. 6 shows the results of simulations for an unheated room with underfloor heating, which in Fig. 6a is drawing position of underfloor heating, pyroelement and intruder inside the room. Fig. 6b depicts the distribution of incident heat flux to the surface of pyroelement and in Fig. 6c is shown course of the heat flux in a vertical section of the pyroelement.

Fig. 7 shows the same situation as Fig. 6 for room heated by underfloor heating.

Vertical heater - unheated room: air temperature 7°C , the heating temperature 5°C

Room with intruder



Room without intruder

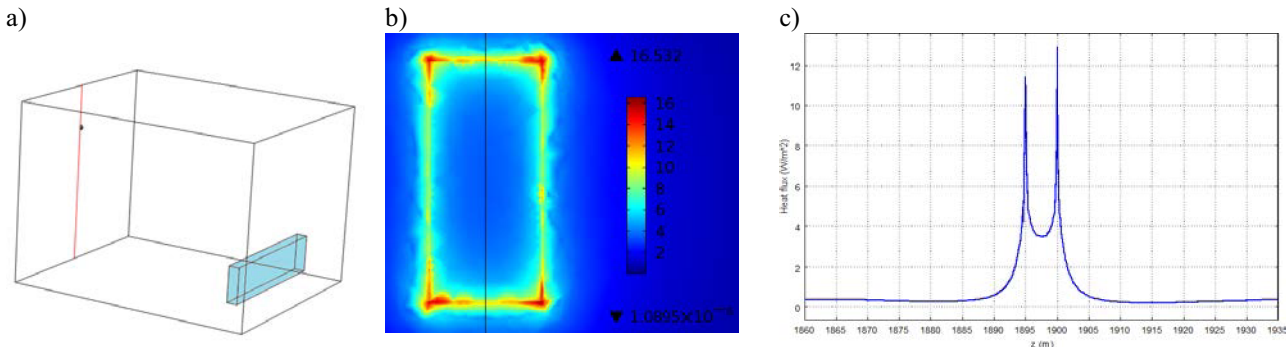
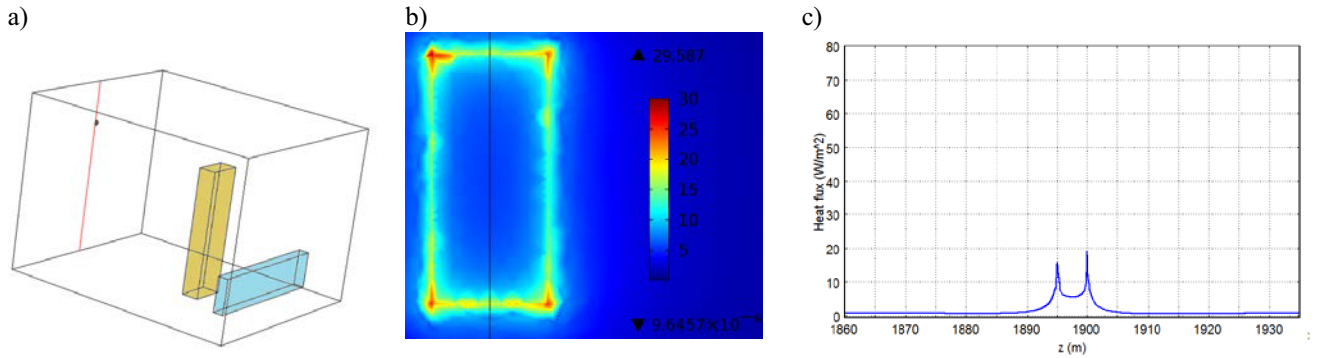


Figure 4. Simulation of heat flux on the surface of pyroelement for unheated room, a- geometric sketch of the model, b - distribution of incident heat flux on the surface of pyroelement, c - course of the heat flux in vertical section.

Vertical heater - heated room: air temperature 24 ° C, heating temperature 37 ° C

Room with intruder



Room without intruder

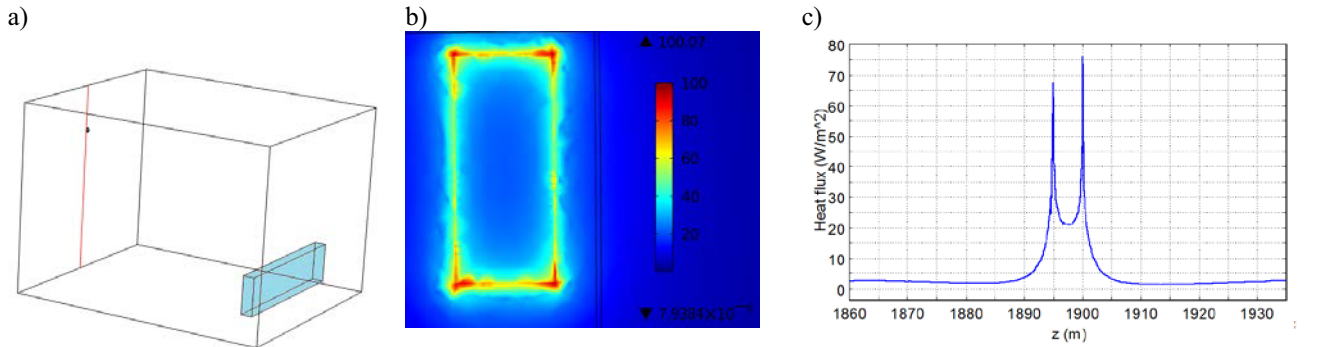
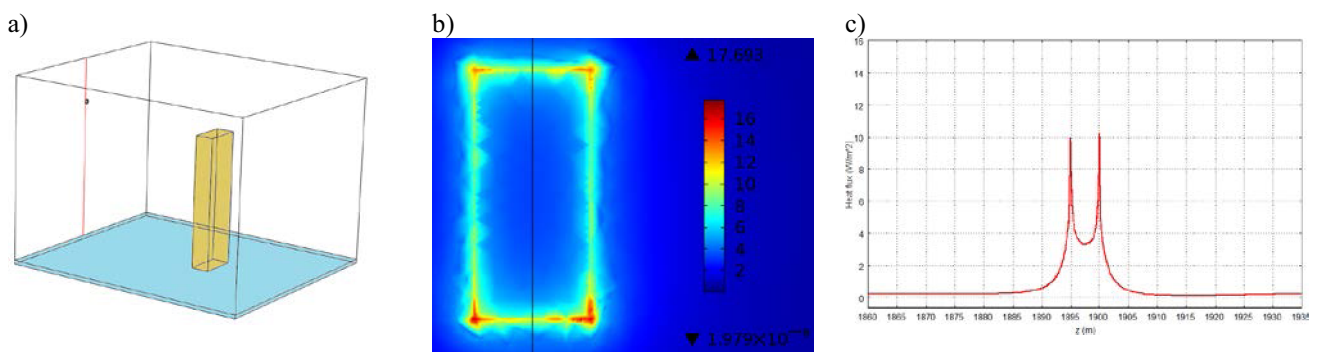


Figure 5. Simulation of heat flux on the surface of pyroelement for heated room, a- geometric sketch of the model, b - distribution of incident heat flux on the surface of pyroelement, c - course of the heat flux in vertical section.

Floor heating - unheated room: air temperature 7 ° C, the heating temperature 5 ° C

Room with intruder



Room without intruder

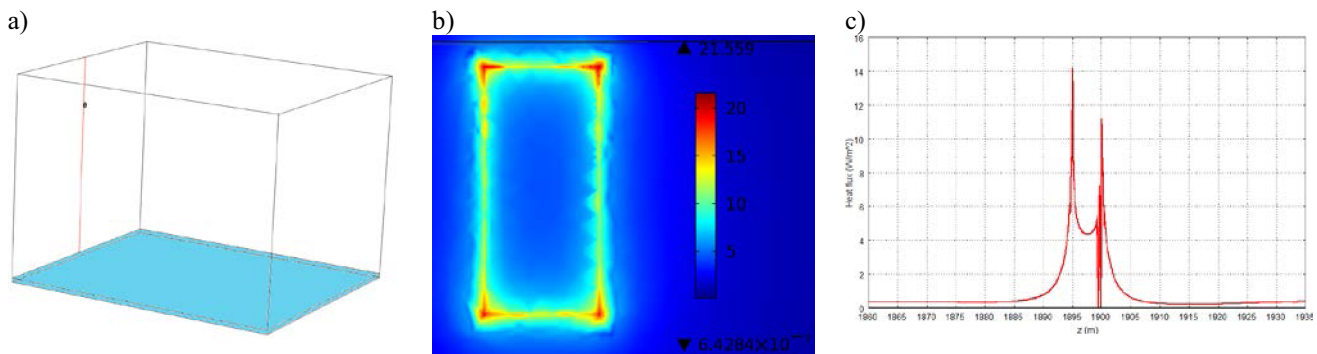
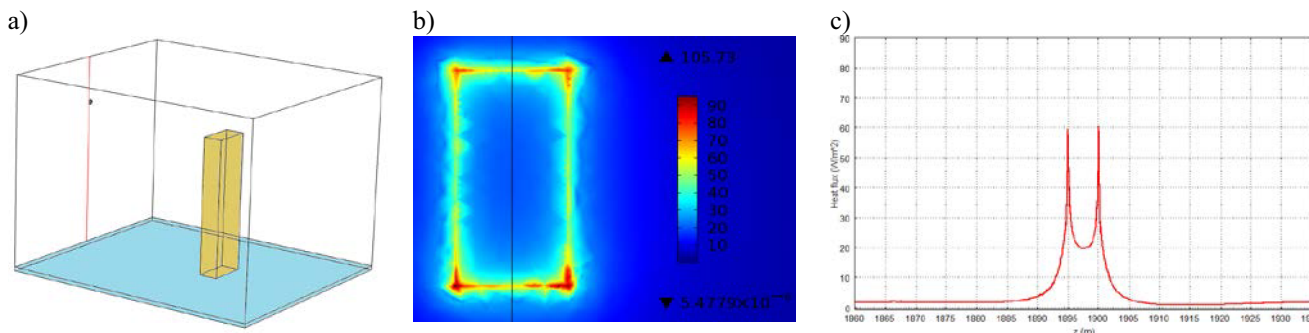


Figure 6. Simulation of heat flux on the surface of pyroelement for unheated room, a- geometric sketch of the model, b - distribution of incident heat flux on the surface of pyroelement, c - course of the heat flux in vertical section.

Floor heating - heated room: air temperature 24 ° C, heating temperature 37 ° C

Room with intruder



Room without intruder

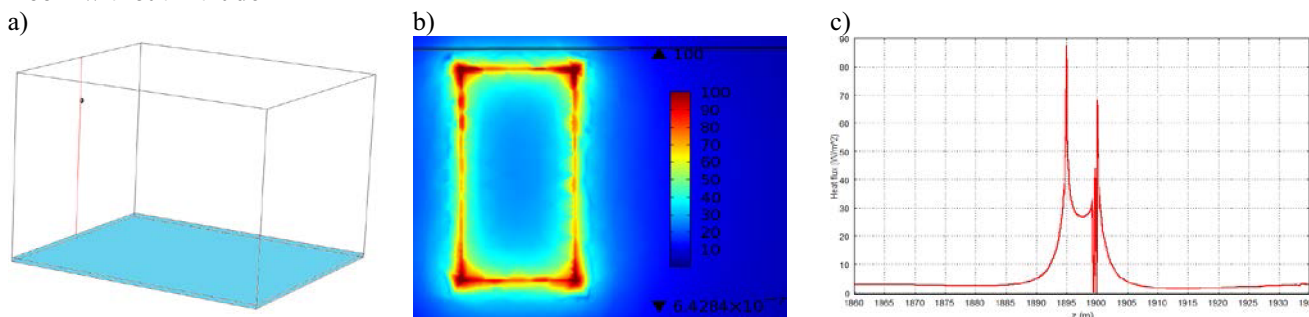


Figure 7. Simulation of heat flux on the surface of pyroelement for heated room, a- geometric sketch of the model, b - distribution of incident heat flux on the surface of pyroelement, c - course of the heat flux in vertical section.

The table 1 shows a summary of the simulation results which are shown in Figs. 4 – 7. The column 2 of the Table1 gives the values of the heat flux in the middle of pyroelement that corresponds to a minimum simulated value.

In the presence of intruder before heater, the heat flux incident on a surface of pyroelement decreased about a significant value which the PIR detector is able to measure.

Table 1. Minimum values of the heat flux on the surface of pyroelement determined by computer simulations.

Vertical heating	
Unheated room without intruder	3.7 W/m ²
Unheated room with intruder	1.3 W/m ²
Heated room without intruder	21 W/m ²
Heated room with intruder	6 W/m ²
Floor heating	
Unheated room without intruder	4.2 W/m ²
Unheated room with intruder	3.75 W/m ²
Heated room without intruder	27 W/m ²
Heated room with intruder	20 W/m ²

6 Conclusion

Based on results of simulations and measurements can be stated that the difference in heat flux incident on a surface of the pyroelement in the room both with the intruder, and also without the intruder will activate the PIR detector. In this way, the intruder can be detected and masked. This confirms the detector's ability to work on

the principle of active detector, i.e. as transmitter and receiver of thermal radiation and evaluation of heat flux changes depending on the type of the heater and the shrouding.

Acknowledgments

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