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Method for Determining the Rational Time Intervals for Detecting Objects by Thermal Imager

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***Abstract*—The developed method allows to provide the maximum possible distance of the thermal imaging observation by determining the rational time intervals of a day when the thermal contrast between object and background is maximal. The method takes into account the influence of cyclic heat transfer in the environment on the change in the recognition properties of the thermal image during the day. This method allows determining the time intervals of the day when the quality of the thermal image will be maximal or minimal.**

Keywords—object, environment, thermal image, time of day

I. Introduction

The level of thermal radiation of object Φ is important, when operator is using thermal imagers. Thermal radiation changes under the influence of heat exchange processes between the object and the environment. Also it depends on the thermo-physical properties of the materials from which the object was produced. Therefore, each object will be detected on a thermal image with varying degrees of probability P. During the day, the level of thermal radiation $\Phi(t)$ have cyclical changes. Determining the time of day, when the level of thermal radiation will be maximum allow to detect objects from a higher distance. But, at the present time, there are no methods to determining time intervals, when using of thermal imager is the most rational.

II. The Formulation Of The Problem

Today there isn't information about availability of techniques for the use of thermal imagers, which take into account the cyclic changes of the recognition properties of the thermal image during the day. The scientific and methodical apparatus for calculating the surface temperature of the objects with cyclic effects of heat exchange processes of the environment is considered in [1-3]. But the problem of detecting objects using thermal imagers is not considered in [1-3]. In [4-6] the focus is on developing technologies (techniques) recognition of multispectral images (including thermal images), discussed issues related to direct detection (shape, contrast, shadow) tell-tale signs of objects. But the influence of the change of environment is not considered.

The cyclic effects of heat exchange processes in the environment on the nature of the distribution of the temperature of the object and background is described in [7-9]. However, in these sources, there are no work on ways to determine rational intervals of time, when the use of thermal imagers is the most efficient. Information obtained by analysis of the thermal image, determined by its quality. The lower the quality gives, less probability to detect the object. Improving image quality is described in the works [4-5, 7]. Authors emphasized that the quality of the image is derived from the hardware perfection of the thermal imager and the conditions for thermal imaging observation.

One of the factors of the conditions is the change of the object and background temperature during the day. Features of thermal imaging observation of objects during the day were investigated in [9-10]. But they were limited just by carry out of experiments. These experiments showed a significant impact on the quality of the thermal image by changing of recognition properties of objects. So, we have the cyclic changes in the recognition properties of the thermal image $P = \{d, x\}$ but don't have prediction of intervals of the day Δt_r, when such properties are maximal $P \to \max$. Solving this problem will allow to obtain a better thermal image, and as a result, increase the maximum possible distance of the object detection $L \to \max$.

III. Method Of Solving The Problem

Equation (1) allows you to take into account the main factors that affect at the probability of object detection:

$$P(t) = \exp\left[-\frac{\ln P_g}{\lg \dfrac{1+K(t)}{1-K(t)}}\left(\frac{d}{x}\right)^2\right], \qquad (1)$$

where $P(t)$ is probability of object detection; t is time of day, hour; P_g is the given value of the probability of object detection; d is spatial disparity in the plane of the object, m; x is linear size of recognizable feature of the object, m; $K(t)$ is thermal contrast [6].

By equation (1), time-varying parameter is the value of thermal contrast $K(t)$. In accordance with the law of Stefan-Boltzmann, thermal contrast describes the ratio of the temperature difference of the object $T_{ob}(t)$ and background $T_f(t)$ to their sum. Equation of the thermal contrast has the form:

$$K(t)=\frac{\varepsilon_{ob}T_{ob}^4(t)-\varepsilon_f T_f^4(t)}{\varepsilon_{ob}T_{ob}^4(t)+\varepsilon_f T_f^4(t)}, \qquad (2)$$

where ε_{ob}, ε_f is radiation ratio of the object and background; $T_{ob}(t)$, $T_f(t)$ is temperature of the object and background, K [11].

Changing of the object and the background temperature during the day and the effect of heat exchange processes can be represented by equation:

$$\begin{cases}\Phi(t)=\sum_{k=1}^{n}\Phi_{c,k}(t)+\sum_{r=1}^{h}\Phi_{rad,r}(t)+\sum_{i=1}^{b}\Phi_{cd,i}(t);\\ \frac{dT(t)}{dt}=a\nabla^2T(t)+\frac{P_v(t)}{c\rho},\end{cases} \qquad (3)$$

where $\Phi_c(t)$, $\Phi_{rad}(t)$ and $\Phi_{cd}(t)$ is heat flux, which comes to the object by convective, radiative and conductive heat exchange, W; n, h and b is discretization of the object by sections what determine convective, radiative and conductive heat exchange; a is coefficient of temperature conductivity, m^2/s; ρ is density, kg/m^3; c is specific heat capacity, J/(kg·K); ∇^2 is the Laplace operator, 1/m; $P_v(t)$ is heat stress, W/m^3 [8].

Solution of equation (3) allows determining the effect of heat exchange processes in the environment by changing the temperature of the object and background during the day. Versatility of equation (3) is possibility to simultaneously take into account all types of heat exchange processes between the environment, object and background.

Determine through equation (1) the distance of thermal imaging observation L. Imagine spatial disparity in the plane of the object d as equation:

$$d=\frac{LD}{f}, \qquad (4)$$

where D is matrix pixel size of the thermal imager, mm; L is distance of thermal imaging observation, m; f is focal length of the thermal imager, m [12];

Substituted at equation (1) equation (4), then:

$$P(t)=\exp\left[-\frac{\ln P_g}{\lg\frac{1+K(t)}{1-K(t)}}\left(\frac{LD}{xf}\right)^2\right]. \qquad (5)$$

From equation (5) we can determine how will change distance of thermal imaging observation during the day:

$$L(t)=\frac{xf}{nD}\sqrt{\log_{P_g}P\cdot\lg\frac{1+K(t)}{1-K(t)}}, \qquad (6)$$

where n is number of pixels what comes to the distinguishing feature of the object.

Based on equations (1) – (6) developed method for determining the rational time intervals for detecting objects by thermal imager.

The implementation of the method involves such assumptions: prognostication of the rational time intervals is carried out on the eve of thermal imaging observation, because of high accuracy of weather forecast; distance of thermal imaging observation is determined from the terms of the task. Method for determining the rational time intervals for detecting objects by thermal imager consists of six steps: first – forecast change of $T_{ob}(t)$ and $T_f(t)$ during the day (equation (3)); second – forecast change of $K(t)$ during the day (equation (2)); third – determination of the number of pixels n, which is necessary for detection of recognizable feature of the object; fourth – forecast change of $P(t)$ during the day (equation (1) or (5)); fifth – plotting $P(t)$; sixth – definition of conditions for which time intervals considered rational Δt_r, and finding time indicators of start and end each of the specified intervals (Fig. 1).

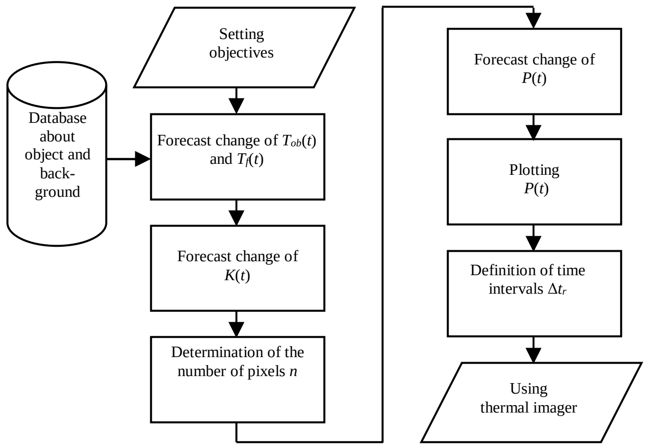


Fig. 1. Scheme of the method

In the first step prognostication $T_{ob}(t)$ i $T_f(t)$ is carried out by means of a solution equations (3), where the methods of the theory of heat and mass transfer are based. Data about thermophysical and mass-dimensional parameters of objects and backgrounds are determined from the reference literature. In the second step by using equations (2) finds changes in thermal contrast $K(t)$ during the day. The value of the radiation factor of the object and the background for different materials is individual and determined from the reference literature.

In the third step it is necessary to determine with what spatial disparity have to find the object. According to Johnson, to detect an object the number of pixels is n = 2…3, recognition – n = 6…9, classification – n = 12…15 and object identification – n > 18.

In the fourth step by using equations (1) or (5) are forecasting of changes $P(t)$ during the day. Equations (1) parameter d determines the scale of the thermal image and depends of distance of thermal imaging observation.

Parameter x determines from the description of the overall dimensions of the object. In equations (5) parameter D and f determines from the data on the tactical and technical characteristics of the thermal imager. Difference between equation (1) and (5) is that in equation (1) you need to have information about the magnitude of the thermal image but in equation (5) you need to have information about tactical and technical characteristics of the thermal imager.

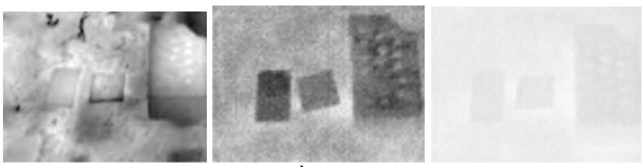
In the fifth step by having received information about changing the probability of object detection $P(t)$ during the day we construct graphic addiction.

In the sixth step by using the given value of the probability of object detection P_g we consider intervals what are rational, when $\Delta t_r \geq P_g$, or irrational $\Delta t_n < P_g$. Then for rational and irrational time intervals, are the numerical values of the beginning and end of each interval. To find distance of thermal imaging observation L in rational time intervals Δt_r if given value of the probability of object detection P_g is used an equation (6).

IV. The Implementation Of The Metod

To check the adequacy of the developed method experimental studies were conducted for a specific "object-background" combination. The results of experimental studies were determined the value of the temperature of the object and the background, thermal contrasts, probability of object detection and rational time intervals. Also, during the experimental studies were determined thermal images to specific "object-background" combination with a frequency of 1 hour throughout the day.

Examples of thermal imaging images obtained during experimental studies presented on Fig. 2 and confirming the impact cyclic heat exchange in the environment to change the recognizable properties thermal image during the day.



a b c

Fig. 2. Thermal images of objects at different times of day (a – 13:00, b – 20:30, c – 5:30)

During the experiment, a change in the values of the temperature of the brick and the soil was studied. The obtained results are presented as graphical dependence on Fig. 3. The research was conducted by using a thermal imager Fluke Ti30 from 13 to 14 august 2017, in the open air without clouds.

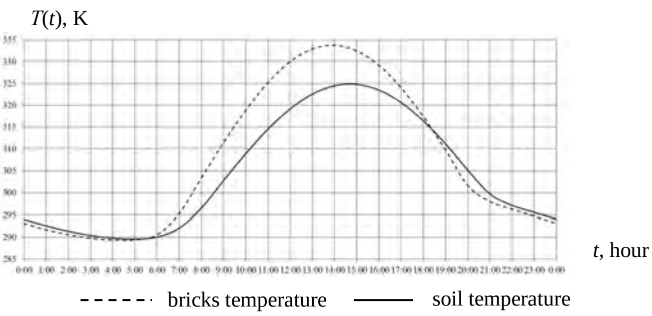


Fig. 3. Change in temperature of object and background during the day

Next, according to equation (1) algorithmically determined value of probability of object detection. Data from Table. 1 were used for calculations. Results of change values probability $P(t)$ are presented on Fig. 4.

TABLE I. Data For The Calculation Of Temperature Change Of The Object And The Background During The Day

Parameters	Object	Background
ε	0,7	0,7
P_g	0,8	0,8
n	8	8
d, m	0,015	0,015
x, m	0,12	0,12

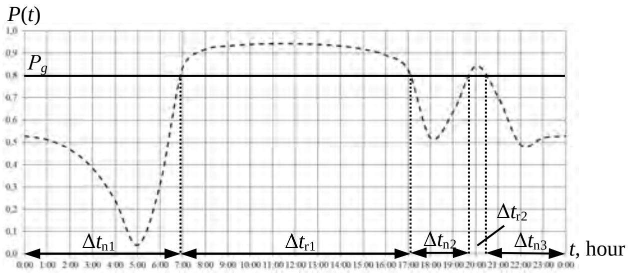


Fig. 4. Change the probability of detecting an object during the day

According to Fig. 4 rational time intervals Δt_r will be: $\Delta t_{r1} \in$ [6:55 – 17:10] and $\Delta t_{r2} \in$ [19:40 – 20:30]. Irrational time intervals Δt_n are: $\Delta t_{n1} \in$ [0:00 – 6:55); $\Delta t_{n2} \in$ (17:10 – 19:40) and $\Delta t_{n3} \in$ (20:30 – 0:00]. Thus, during the day is observed 2 rational and 3 irrational time intervals for using thermal imager.

To definition of numerical values of efficiency of use a thermal imager in rational time intervals by equation (6), we should calculated value of distances. This distance guarantees the detection of an object with given value of the probability P_g in rational Δt_r and Δt_n irrational time. Next is determined by how many times distances guarantees the detection of an object in rational time intervals L_r bigger then in irrational time intervals L_n. Under distance, the guaranteed detection of an object is understood as a distance, which fulfills the condition $P(t) \geq P_g$. Data for calculations was used from Table. 2. Results of calculations distance of thermal imaging observation for bricks on the background of the soil during the day for thermal imager Fluke Ti30 presented on Fig. 5.

TABLE II. Data For Calculation Of Change Distance Of Detection Of The Object During The Day

Parameters	Value
P	0,8
D, м	0,000025
f, м	0,025

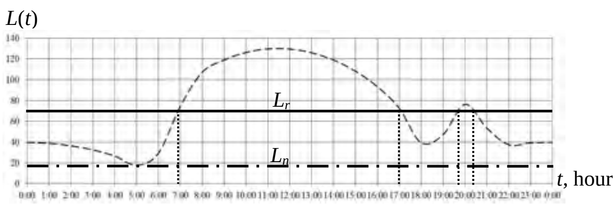


Fig. 5. Figure 5. Change the detection distance of the object during the day

According to Fig. 5 L_r = 74,5 m and L_n = 17,7 m. Thus, the use of the method allows guaranteed to detect an object in rational time intervals from distance, that in 4,2 times higher than the same value at irrational time intervals.

V. Conclusion

The results of the scientific research carried out are important for the field observation of objects in conditions of low contrast of the images. Immediately, the research results can be used when planning the time of day for using thermal imager.

New method for determining the rational time intervals for detecting objects by thermal imager based on the consideration of cyclic heat transfer in the environment. This will increase the detection range of objects by thermal imagers due to their use at rational intervals of the day for a given value of thermal contrast or the likelihood of detecting an object. The recognition properties of the thermal image will be maximally possible at rational intervals of the day.

The results of experimental studies to determine the change in the distance of detection of an object (brick) on the background of the ground during the day. According to the results of experimental studies, it can be argued that using of new method allows to reveal rational time intervals when guaranteed to detect of object carried out with the given value of the probability for a specific type of thermal imager, from distance, that in 4,2 times higher than the same value at irrational time intervals.

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