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TEMPORAL, SPATIAL, AND COMPOSITIONAL VARIABILITY OF THE INFRARED SIGNATURE OF OBJECTS

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Abstract. The property of dynamic variability of natural and technical objects has been studied. It is noted that structural objects made of different materials have a dynamic, i.e., time-dependent infrared signature, which is caused by the difference in heating and cooling rates of various materials. An optimization problem for minimizing the infrared signature of complex objects made of different materials has been formulated. It is shown that the dynamic infrared signature of composite objects heated to a certain temperature can be minimized if the cooling rate of the parts follows an exponential law that is logarithmically inversely proportional to the range of their temperature change.

Keywords: Pinfrared signature, temporal dynamics, optical radiation, cooling, optimization.
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1 Introduction

It is well known that the infrared signature of a homogeneous object is determined by calculating the area of the radiating surface and the temperature, which together with the material's emissivity determine the density of the emitted optical radiation (Rao, 2011; Baranwal et al., 2019; Mahulikar et al., 2002; Beaupré et al., 2009). However, such a definition of the infrared signature of an object can only be applied to the object and the environment in a static state, i.e., not changing over time and space. Obviously, real objects are always influenced by external meteorological factors such as ambient temperature, wind, dew formation, air dustiness, etc. Therefore, the physical properties of substances under external influence are widely studied (Popov et al., 2024; Jabarov et al., 2023; Asadov et al., 2008; Azimova et al., 2020; Abiyev et al., 2024). These factors lead to changes in the actual temperature of the object, as well as its emissivity (Reinov et al., 2008). The influence of wind on the infrared radiation of underground and surface mines is discussed in Remke (2004). In general, the dynamics of temperature measurements of an object, according to Remke (2004), are determined by the heat balance equation

$$\rho c d \cdot \frac{dT}{dt} = E_{abs} - E_{lost}, \tag{1}$$

where ρ - is the material density, c - is the specific heat capacity, d - is the thickness of the object, T - is the temperature; t - is time, E_{abs}- is the total heat flux absorbed by the object, defined as

$$E_{abs} = \alpha \left[E_{sky} + E_{sol} + E_{ground} + E_{relf} \right], \tag{2}$$

where E_{sky}- is the sky radiation, E_{sol} - is solar radiation, E_{ground} - is the emissive radiation of the ground, E_{refl}- is the reflected radiation from the Earth's surface. E_{lost}-is defined as

$$E_{lost} = E_{rad} + E_{conv}, \tag{3}$$

where E_{rad}-is the emissive radiation of the object; E_{conv} - is the convective heat loss of the object. The solution to equation (1) is usually carried out with the initial temperature $T(t = 0)$ specified.

Temporal changes in E_{abs} lead to significant differences between the measured and modeled values of the solution to equation (1) (Bergman et al., 2011; Iersel et al., 2016), as shown in Fig. 1 *a*,*b* (Iersel et al., 2016).

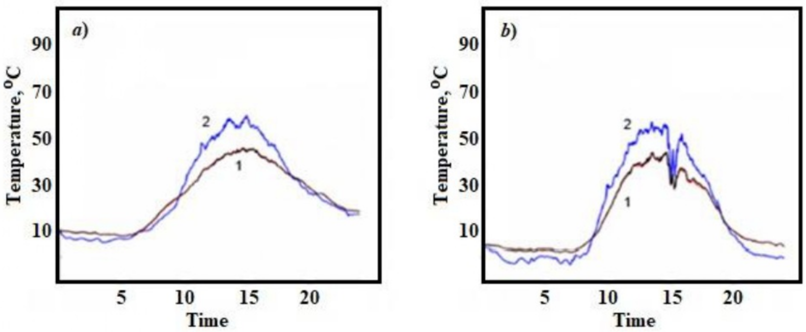

Figure 1: Modeled and measured values of (1) object temperature at different times. (*a*) – June 30, 2015; (*b*) – August 9, 2015 (Iersel *et al.*, 2016).

Extreme studies conducted in (Bergman *et al.*, 2011) showed that the decrease in object temperature can be modeled by the equation

$$T(t) = (T_f(t_{start}) - T_f(t_{end}))\exp(-0,03t) + T_f(t_{end}), \tag{4}$$

where $T_f(t_{start})$ is the initial temperature of the object at time tstart$tstart$; $T_f(t_{end})$ is the final temperature of the object at time t_{end}. However, these experimental studies showed that the following model generalization of equations of type (4) obtained at different times

$$f(t) = a\exp(-bt) + c. \tag{5}$$

Has non-constant values of the coefficients *a*, *b*, and *c*. For example, over a two-month interval, coefficient aa varied within (19.2 - 18.7), b – (0.030 - 0.026), c – (16.4 - 23.6).

According to the statement in Iersel et al. (2016), this result corresponds to Newton's law, which states that the rate of temperature change of an object during cooling is proportional to the temperature difference between the object and the environment. However, changes in the value of *b*, according to Iersel et al. (2016), occurred both under conditions of changes in wind speed and direction, as well as changes in ambient temperature.Therefore, we can speak of the spatial variability of the object's temperature, considering the spatial variability of the interaction between wind and the object.If the object under study has a complex structural composition, including materials with different densities and heat capacities, as well as different thicknesses, then, taking into account expression (1), we can speak of a compositional dependence of the temperature and infrared signature of such an object. The purpose of this article is to study the changes in temperature and signature of such objects.

2 Materials and Methods

Consider a model of a composite structure containing nn elements, whose coefficient b varies within certain limits

$$b = (b_{min} \div b_{max}).$$

At the same time, as stated above, bb can vary both depending on meteorological factors and on the type and geometric parameters of the structural components of the object. In general, it can be assumed that the coefficient b changes as a result of the influence of a single equivalent factor z, defined as a linear superposition

$$z = a_1 x_1 + a_2 x_2, \tag{6}$$

where a_1,a_2 are weighting coefficients; x_1- is an external factor characterizing the influence of meteorological factors; x_2- is an internal factor characterizing the physical and structural parameters of a certain element of the object.Further, let us assume that a composite object is characterized by an ordered set

$$z = \{z_i\}; i = \overline{1, n},$$

where $z_i = z_{i-1} + \triangle z$; $\triangle z = const$; $z_0 = 0$.

Let us introduce a discrete function

$$L_i = \psi(z_i). \tag{7}$$

In the generalized model equation (5), replacing a with z_i, taking into account (7) can be written

$$f(t)_i = z_i \exp[-\psi(z_i)t] + C_i. \tag{8}$$

For the entire composite object consisting of n parts is obtained

$$\gamma = \sum_{i=1}^{n} f(t)_i = \sum_{i=1}^{n} [z_i \exp[-\psi(z_i)t] + C_i]. \tag{9}$$

In the general case, we can formulate the problem of finding such an optimal function $\psi(z_i)$ at which the indicator γ reaches an extreme value. To solve this issue, we impose the following restrictive condition on the function $\psi(z_i)$

$$\sum_{i=1}^{n} \psi(z_i) = C_1. \tag{10}$$

Next, to calculate the optimal form of the function $\psi(z)$, we use continuous equivalents of discrete functions (9) and (10), based on which we compose the objective functional γ where

$$\gamma = \int_{z_{min}}^{z_{max}} z\exp[-\psi(z)t]\, dz + \psi\left[\int_{z_{min}}^{z_{max}} \psi(z)\, dz - C\right] + C_2(z_{max} - z_{min}), \tag{11}$$

where η - is the Lagrange multiplier.

According to [8], the solution to the optimization problem (11) satisfies the condition

$$\frac{d\{z\exp[-\psi(z)t] + \psi\ \eta(z)\}}{d\psi(z)} = 0. \tag{12}$$

From condition (12) is obtained

$$z\exp[-(z)t]\ (-t) + \eta = 0. \tag{13}$$

From expression (13) we find

$$\exp\left[-\varphi\left(z\right)t\right]\ =\frac{\eta}{tz}. \tag{14}$$

Taking the logarithm of both sides of (14) we have

$$\varphi\left(z\right)=\frac{1}{t}\ln\frac{tz}{\eta}\ . \tag{15}$$

To calculate the Lagrange multiplier, we use expression (15) and the continuous equivalent of the discrete sum (10). We have

$$\int_{z_{min}}^{z_{max}}\frac{1}{t}\ln\frac{tz}{\eta}\ dz=C_1. \tag{16}$$

We rewrite expression (16) as

$$\int_{z_{min}}^{z_{max}}\frac{1}{t}\ln tz\ dz-\int_{z_{min}}^{z_{max}}\frac{1}{t}\ln\eta\ dz=C_1. \tag{17}$$

From equality (17), is found

$$\ln\eta\ \left(z_{max}-z_{min}\right)=\int_{z_{min}}^{z_{max}}\ln tz\ dz-C_1t. \tag{18}$$

From expression (18) we get

$$\ln\eta\ =\frac{\int_{z_{min}}^{z_{max}}\ln tz\ dz-C_1t}{z_{max}-z_{min}}. \tag{19}$$

From expression (19), we obtain

$$\eta=\exp\left[\frac{\int_{z_{min}}^{z_{max}}\ln tz\ dz-C_1t}{z_{max}-z_{min}}\right]\ . \tag{20}$$

Taking into account expressions (15) and (20), we find

$$\varphi\left(z\right)=\frac{1}{t}\ln tz\ -\frac{1}{t}\left[\frac{\int_{z_{min}}^{z_{max}}\ln tz\ dz-C_1t}{z_{max}-z_{min}}\right]=\frac{1}{t}\ln\frac{tz\left(z_{max}-z_{min}\right)}{\left[\frac{\int_{z_{min}}^{z_{max}}\ln tz\ dz-C_1t}{z_{max}-z_{min}}\right]}\ . \tag{21}$$

Thus, the objective functional γ reaches an extremum if the temperature of the composite object is logarithmically dependent on zz, changing in a complex manner over time. To determine the type of extremum, we use the Lagrange criterion and calculate the second derivative of the integrand in (11). We have

$$\frac{d^2\left\{z\exp\left[-\psi\left(z\right)t\right]+\psi\eta\left(z\right)\ \right\}}{d\psi\left(z\right)^2}=zt^2\exp\left[-\varphi\left(z\right)t\right]\ . \tag{22}$$

As can be seen from expression (22), the result has a positive sign, i.e., the extremum is a minimum.

Thus, the issue of the formation of the dynamic infrared signature of real objects under the influence of various meteorological factors has been considered. In particular, the issue of cooling heated objects and the influence of such cooling on the formation of a time-varying infrared signature has been considered. It is noted that the infrared signature in real cases can vary over time, space, and depending on the compositional structure of complex objects made of different materials. A problem of minimizing the infrared signature of complex objects made of different materials has been formulated and solved. As a result of solving the optimization problem, it has been determined that the total infrared signature of such objects can be minimized if the exponential cooling rate of individual parts is logarithmically inversely proportional to the entire range of temperature change of these parts during cooling.

3 Conclusion

It has been determined that composite objects made of different materials have a time-dependent (dynamic) infrared signature, which is caused by the unequal heating and cooling rates of parts made of different materials.

1. An optimization problem for minimizing the infrared signature of composite objects made of different materials has been formulated and solved.

2. It has been determined that the dynamic infrared signature of composite objects heated to a certain temperature can be minimized if the cooling rate of the parts follows an exponential law that is logarithmically inversely proportional to the range of their temperature change.

References

Abiyev, A.S., Huseynov, E.M., & Hashimov, R.F. (2024). Gamma radiation-induced alterations in nanocrystalline titanium nitride (TiN) particles: A structural perspective. *Radiation Physics and Chemistry*, *218*, 111638. https://doi.org/10.1016/j.radphyschem.2024.111638

Asadov, Yu.G., Alyev, Yu.I., & Jafarov, K.M. (2008). X-ray diffraction study of compounds in the Ag_2S-Cu_2S system. *Inorganic Materials*, *44*, 460-466. https://doi.org/10.1134/S0020168508050051

Azimova, S.R., Abdullayev, N.M., Aliyev, Y.I., & Mirzayev, M.N. (2020). Effect of the $Se \rightarrow Te$ substitutions on thermal properties of binary Bi_2Se_3 semiconductor. *Modern Physics Letters B*, *34*, 2050156. https://doi.org/10.1142/S0217984920501560

Baranwal, N., Mahulikar, S.P. (2019). Review of infrared signature suppression systems using optical blocking method. *Defence Technology*, *15*, 432-439. https://doi.org/10.1016/j.dt.2018.12.002

Beaupré, S., Breton, A.C., Dumas, J., & Leclerc, M. (2009). Multicolored electrochromic cells based on poly (2,7-Carbazole) derivatives for adaptive camouflage. *Chemistry of Materials*, *8*, 1504-1513. https://doi.org/10.1021/cm802941e

Bergman, T.L., Lavine, A.S., Incropera, F.P., & Dewitt, D.P. (2011). *Fundamentals of Heat And Mass Transfer*. 7^{th} edition, John Willey & Sons, 1048.

Iersel, M., Veerman, H.E., Cohen, L.H., Benoist, K.W., Binsbergen, S.A., Riggelen, F. (2016). The influence of environmental parameters on dynamic infrared signatures. *Proceedings of SPIE - The International Society for Optical Engineering*, *9979*, 99790T. https://doi.org/10.1117/12.2239474

Jabarov, S.H., Nabiyeva, A.Kh., Trukhanov, A.V., Trukhanov, S.V., Huseynov, H.J., & Aliyev, Y.I. (2023). Dielectric and electrical properties of the $La_{0.73}Ba_{0.27}MnO_3$ compound at high temperatures. *SOCAR Proceedings*, *4*, 171-175. http://dx.doi.org/10.5510/OGP20230400931

Jafarov, M.A., Nasirov, E.F., Mammadov, H.M., & Chanmammadova, E.A. (2019). Properties of Por. Si-ZnSTe: Cr nanocrystalline thin films. *Chalcogenide Letters, 16*(3), 131-135.

Popov, E.P., Donkov, A.A., Trung, N.V.M., Samadov, S.F., Sidorin, A.A., Orlov, ... , & Mirzayev, M.N. (2024). Analyzing point defect polarization in tungsten and tungsten carbide under high gamma irradiation for radiation shielding applications. *International Journal of Refractory Metals and Hard Materials*, *124*, 106850. https://doi.org/10.1016/j.ijrmhm.2024.106850

Rao, A.G. (2011). Infrared signature modeling and analysis of aircraft plume. *International Journal of Turbo & Jet-Engines*, *28*, 187-197. https://doi.org/10.1515/tjj.2011.023

Mahulikar, S.P., Sane, S.K., Gaitonde, U.N., & Marathe, A.G. (2002). Numerical studies of infrared signature levels of complete aircraft. *The Aeronautical Journal*, *105*, 185-192. https://doi.org/10.1017/S0001924000025422

Reinov, A., Bushlin, Y., Lessin, A., & Clement, D. (2008). Dew, dust, and wind influencing thermal signatures of objects, *Proceedings of SPIE - The International Society for Optical Engineering*, *6941*, 69410U. https://doi.org/10.1117/12.781548

Remke, L., Borchers, B., Hendrickx, J. M., & Hong, S. (2004). Controlled field experiments of wind effects on thermal signatures of buried and surface-laid land mines. *Proceedings of SPIE - The International Society for Optical Engineering*, *5415*, 648-657. https://doi.org/10.1117/12.540700