Use of infrared radiometry in temperature measurement of wild animals

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Abstract – **The aim of our present work is to show the importance of infrared radiometry in conducting various animal studies in their natural living conditions. We want to show what difficulties exist when measuring from the air. We have explored numerical examples of temperature measurement at different solid angles and different wild animals.**

Keywords – **infrared radiometer, wild animals, solid angle**

I. Introduction

In modern times, infrared radiometry has entered many sectors: human and veterinary medicine, agriculture, livestock, energy, construction, security, defense and military, search and security activities, state border control, space research, etc.

Much of modern medicine such as rheumatology and dermatology uses infrared radiometry to provide diagnostic information. It is also used in the investigation of vascular dysfunction, wounds from burning, frosting as well as in the fight against cancer [1-4].

Infrared radiometry is a technique for remotely measuring temperature in a certain area of space. The aim is to capture, visualize and record changes in temperature [5-10]. Raising the surface temperature of the skin leads to an increase in body radiation. This is the result of increased metabolic activity, which in turn can be caused by inflammatory, metabolic and toxic factors. It has long been known that this may be a natural indicator of disease or a variety of deviations from normal life processes [11-14].

Infrared radiometry makes it possible to monitor and control the health status of animals in the wild [15-24]. A healthy organism is characterized by an even distribution of temperature between different parts of the body. Many pathological processes and illnesses arise through local changes in heat production, altering the pattern of blood flow in affected organs or tissues. Thanks to blood flow and the conductive transfer of heat from body depth to its surface, infrared images are thought to be able to reflect deeply the body processes [11,12].

In wildlife, radiometry can be used for early diagnosis and monitoring of severe contagious diseases such as foot and mouth rabies, for example. It was found that a rise in body temperature could occur before the onset of clinical symptoms. There are studies showing the possibilities of infrared radiometry to detect very serious and deadly diseases in animals such as plague, influenza, tuberculosis and others. It is essential for medicine, ecology, animal husbandry and all related sciences and economics to obtain quick and reliable information on the factors that affect animal populations and their interactions with the surrounding environment [13]. Infrared radiometry enables remote monitoring of the physical and physiological parameters of different animal species. It is a non-invasive, non-contacting and harmless method of visualization, both day and night, as the luminance in the visible spectrum is not essential. The ability to perform such observations on animals, in their natural habitat, from the air makes it a very preferred and important mechanism for various research.

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II. Theory

The light propagation in a scattering and absorption medium can be strictly studied by using the classical electrodynamic theory and the partial coherence theory. We prefer to use the radiometric (energy) approach to the analysis of the respective phenomena, which is clearer in terms of physics and simpler in terms of mathematics [5,6,25]. This approach leads to the composition of the so-called propagation equation. This equation can be used only in the cases contained in the scope of proper application of radiometric concepts.

In order to analyze the situation, we use the spectral density of the elementary area emission in the whole half-space 2π sr

$$M_\lambda = \frac{(d^3 \Phi)_{2\pi}}{dA\, d\lambda} . \qquad (1)$$

If the emitting body is in thermal equilibrium with the environment (1), the Planck law is used (Planck law for black body radiation)

$$M_\lambda^*(\lambda, T) = \frac{c_1}{\lambda^5\left[exp\left(\frac{c_2}{\lambda T}\right)-1\right]} \qquad (2)$$

where the constants are defined [25] :

$$c_1 = 2\pi c^2 h = 3{,}74.10^{-16} W m^2 ,$$
$$c_2 = ch/k_B = 1{,}44.10^{-2} mK .$$

In the expression, the * denotes that we refer to a black body.

For a better analysis of the situation, in the space we use a dimension which is related not only to the elementary radiation area like in (1) but also to the solid view angle and observation angle

$$L_\lambda = \frac{d^5 \Phi}{d\Omega\, dA\, d\lambda\, cos\theta} \quad . \qquad (3)$$

If the radiation area is isotropic, then the relation between the formulae is simplified to

$$L_\lambda^*(\lambda, T) = \frac{1}{\pi} M_\lambda^*(\lambda, T) \quad . \qquad (4)$$

In nature, bodies are more or less different from the idealization of the black body. Therefore, we use the emissivity coefficient

$$\varepsilon(\lambda, T) = \frac{M_\lambda\ (\lambda,T)}{M_\lambda^*(\lambda,T)} \quad . \qquad (5)$$

When we are considering a situation on Earth [26-28], it is always necessary to take into account the influence of the atmosphere. As an example, we will study the atmospheric channel of one specific radiometric system situated between the emitting surface and the aperture of the receiving antenna (fig.1).

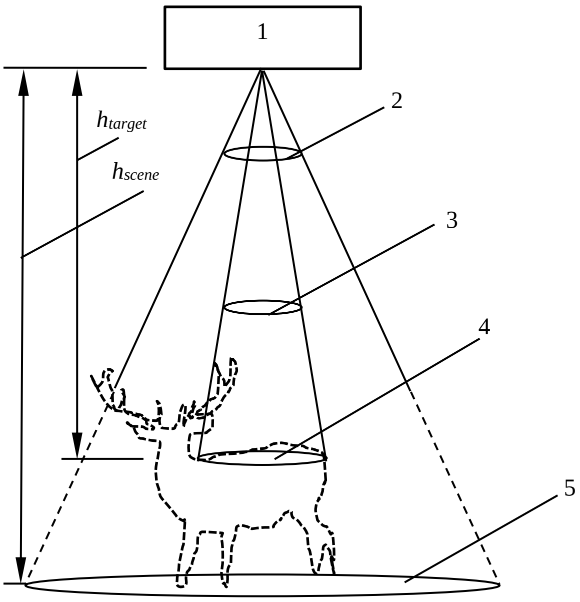

Fig. 1. General set-up of a wild animal radiometric investigation (1-radiometric device; 2-solid view angle of the radiometric device; 3-solid view angle of the animal investigated; 4-essential area of the wild animal surface which produces radiation (target); 5-radiation from the surface on which the animal is located (scene), h_{target} - distance to the target, h_{scene} – distance to the scene)

The propagation environment is characterized by volume coefficients of scattering and absorption, with an ensemble scattering indicatrice and the respective temperature. In this paper we will not consider the polarization effects during light propagation.

In the volume between the source and the measuring device, we can observe interactions of optical radiations with the atmospheric substance and energy transformations. The most essential ones among them are the scattering and absorption. The unified effect termed extinction (the reducing of energy) is often used.

Another important effect is that the substance in the volume between the source and the measuring device is a source of heat radiation whose energy is distributed along the spectral scale, depending on the temperature in that volume. One part of this radiation is directed to the receiver and added to the radiation of the object investigated.

The third essential effect is that, in the volume between the source and the receiver, it is possible for other radiations to enter, which are propagated along different spatial axes. Some of them can be determined by independent outside sources, while others are the result of multiple scattering of the radiations from the aerosol particles and the molecules of the gases.

The task of propagation can be formulated as a differential equation [25]

$$\frac{dL_\lambda}{dz} = -\left(\alpha^{(s)} + \alpha^{(a)}\right) L_\lambda + \alpha^{(a)} L_\lambda^* + \alpha^{(s)} L_{\lambda_{scattered}} \qquad (6)$$

where $\alpha^{(s)}$ is the atmosphere scattering coefficient, $\alpha^{(a)}$ is the atmosphere absorption coefficient. $L_{\lambda_{scattered}}$ is the ingredient determined by the scattering from other sources. We will assume, in our case, that this ingredient is too low and rewrite (6) without it.

$$\frac{dL_\lambda}{dz} = -\left(\alpha^{(s)} + \alpha^{(a)}\right) L_\lambda + \alpha^{(a)} L_\lambda^* \ . \qquad (7)$$

In order to derive the flux which would enter the photoreceiver, we have to solve (7) and multiply by the values of the aperture and the solid angle

$$\Phi_{\lambda,r} = A_r\, \Omega_r\, L_\lambda\, (Z) \ . \qquad (8)$$

We derive the solution of the differential equation by assuming that the atmospheric scattering and absorption coefficients are constants in terms of space and spectrum. This is possible because the distance is relatively small and we are also using a small part of the spectrum.

We also assume that the sources of radiation are isotropic.

After these assumptions, we derive an expression for the optical flux, which enter the receiver (we use (1)..(8))

$$\Phi_r = A_r\, \Omega_r\, \tau_r\, \left\{\varepsilon_t \left\{exp\left[-\left(\alpha^{(s)} + \alpha^{(a)}\right)Z\right]\right\} U(T_t; \lambda_1, \lambda_2) + \right.$$
$$\left. + \frac{\alpha^{(a)}}{\alpha^{(s)} + \alpha^{(a)}} \left\{1 - exp\left[-\left(\alpha^{(s)} + \alpha^{(a)}\right)Z\right] U(T_a; \lambda_1, \lambda_2)\right\}\right\} \qquad (9)$$

where

$$U(T_t;\lambda_1,\lambda_2) = \int_{\lambda_1}^{\lambda_2} L_\lambda^* (\lambda,T) d\lambda \qquad (10)$$

and τ_r is the transparency of the receiver's optics.

We can summarize that the flux is formed by two main ingredients in (9): the one from the targets and the one from the atmosphere

$$\Phi_r = \Phi_t + \Phi_a \ . \qquad (11)$$

III. Numerical Investigation

In order to make the general theory useful, we will consider a specific example with a radiometric investigation of a deer. The solid angle of the radiometric device is fixed. The angle, however, at which we see the considerable part of the animal's body that we are interested in, changes depending on the height. For this reason, in order to make a more accurate assessment of the entering of different optical fluxes in the entrance aperture of the receiver, we modify (11) to

$$\Phi_{t,total} = \Phi_t \ (\Omega = \Omega_t \ ; Z = h_t \ ) +$$
$$+ \Phi_{scene}(\Omega = \Omega_r \ - \Omega_t \ ; Z = h_{scene}) \qquad (12)$$

and

$$\Phi_{a,total} = \Phi_{a,t}(\Omega = \Omega_t \ ; Z = h_t \ ) +$$
$$+ \Phi_{a,scene}(\Omega = \Omega_r \ - \Omega_t \ ; Z = h_{scene}) \qquad (13)$$

In order to derive a plausible numerical simulation, we use the literature about the respective wild animal, in this case the deer. Most of the objects investigated have a complex shape, which leads to measurement errors. Bodily surfaces also have a serious impact. The presence of fur has a significant influence on the surface temperature of the body and, accordingly, is of significant importance. Animals with thick fur are poorly visible, while those whose body is barely covered with fur are more suitable for research. The density of the fur, the individual features of the fur, its length and purity have a significant impact. The purity of the surface of the examined tissues is important, as is their coloring. For example, the presence of moisture, grease, dust adhesion or other physical particles on the surface of the skin affect the measurement results.

Behavioral factors also have an impact. Observations and studies of wildlife are accompanied by many problems due to the unique biological and behavioral traits of different species, such as hiding in hiding places. The behavior and reactions of wildlife species resulting from changes in environmental factors cannot be predicted. Serious influence is also caused by intrinsic factors such as sweat evaporation, vascular perfusion, local tissue metabolism. The stress factor is essential and can seriously affect the results of the research.

For this reason, radiometric analyses should be performed in a natural environment when the subject is adapted to the environment.

For the simulation, we select the following data [28,29]: $T_a = 293K$, $T_t = 313K$, $T_{scene} = 293K$, $\lambda_1 = 8\mu m$, $\lambda_2 = 13\mu m$, $\varepsilon_t = 0{,}99$, $\varepsilon_{scene} = 0{,}98$, $\alpha^{(s)} = 0{,}03 km^{-1}$, $\alpha^{(a)} = 0{,}4 km^{-1}$, $\Omega_r = 6.10^{-3} sr$, $A_r = 8.10^{-5} m^2$, $\tau_r = 1$.

Using (2) and (4) we perform numerical integration of expression (10). For this we use Scilab [30]. After that we perform calculations for (12) and (13). Part of the results are shown in the following Table I.

TABLE I
PART OF SIMULATION DATA

No	1	2	3	4
$h_{scene}[m]$	10,13	12	14	16
Φ_t $[W]$, T=313K	2,7027 $.10^{-05}$	1,8598 $.10^{-05}$	1,3304 $.10^{-05}$	9,9848. 10^{-06}
$\Phi_{all\ other}$ [W] , T=293K	7,3266 $.10^{-08}$	6,1923 $.10^{-06}$	1,0035 $.10^{-05}$	1,2445 $.10^{-05}$

We are particularly interested in the comparison of the flux coming from the target with the sum of the fluxes from the atmosphere and the flux from the scene. The results are shown graphically in figure 2.

IV. Conclusion

Applying high-level infrared imaging opens up new serious possibilities. The method allows for large areas and many objects to be covered. It is a reliable mechanism for counting populations, detecting and registering habitat areas, exploring migratory processes, identifying the ways and rules for moving in large herds, studying the natural habitat of certain groups, and animal breeds in the wild. In this case, it is important to note that radiometry is used not for accurate temperature measurements but for detecting objects with temperatures significantly different from those of the surrounding environment (fig.2). It also provides us with a good opportunity to find newborns or small ones hidden in the forest.

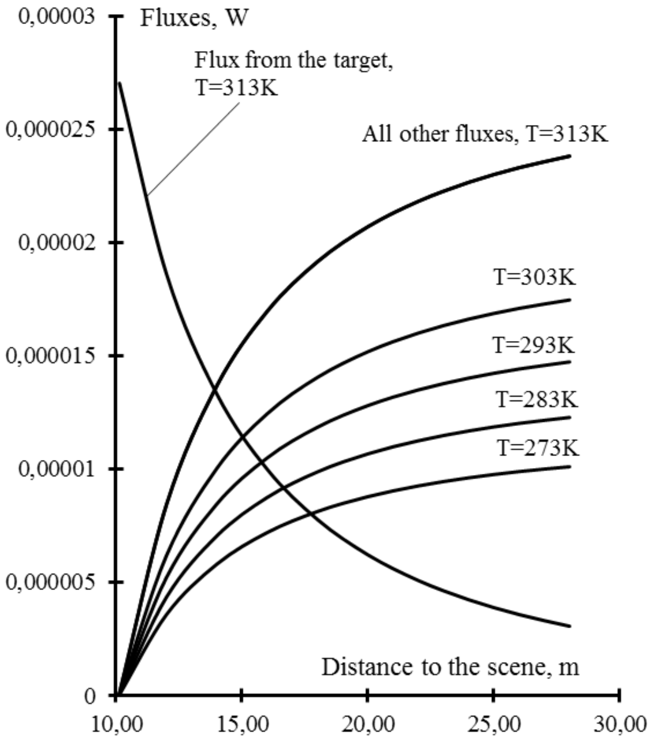

Fig. 2. Simulation for one type of target with temperature 313K and emissivity coefficient 0,99 (wild animal) and different temperatures for a scene with emissivity coefficient 0,98 and atmosphere.

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