Use of infrared radiometry in temperature measurement of plant leaf

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Abstract – **Through our present work we will show the importance of infrared radiometry in conducting various plant studies. We will look at the factors that affect temperature measurements and their significance. We will draw conclusions about the significance of the distance between the thermal camera and the object of study.**

Keywords – **infrared radiometry, infrared thermography, agriculture, solid angle**

I. Introduction

Infrared thermography (IRT) plays an important role in some methods of assessing the condition of different vegetative tissues. It is a key tool in developing a non-invasive analysis of plant metabolism. It also helps diagnose and monitor various phytopathogenic processes. The use of modern sensor matrices allows the thermographic images to be produced at high resolution, allowing for early diagnosis of plant diseases when the affected tissue is a small percentage and tissue contamination levels are low. Infrared thermography is used in methods to test the viability of seedlings [1-8].

Remote sensing and thermal imaging analysis are methods of collecting, processing and interpreting data without physical contact between the measuring device and the object so that it can be analyzed repeatedly and harmlessly [9-12]. All surrounding objects, thanks to their own temperature, emit infrared (IR) radiation. Thermal imaging is performed with detectors sensitive to a wavelength of 8 to 12μm. The image we see represents variations in the temperature of the leaves. IR thermography is used to plan irrigation, to evaluate plant-pathogen interactions through models of surface temperature monitoring of the leaves and to fully monitor their interaction with the environment [13-18]. The lack of need for contact with the object of research makes it particularly suitable for remote monitoring and data collection. It is also preferred as it is as harmless as possible to plants and the environment.

IRT is used in studying plant temperature stress processes, their adaptation, their ability to acclimate, their endurance and survival in cold weather conditions.

Various pests and diseases hinder growth and reduce crop yields. They can change the temperature and water balance of the plants. The thermophagus could be used to monitor and create patterns of various diseases or pest infestations and detect them before the occurrence of visible symptoms. It works well in field conditions to locate places where culture is more affected and therefore requires more urgent intervention [19,20]. It also allows for the monitoring of the content of different nutrients in crops. In this way, the processes of fertilization and soil incorporation of the ingredients necessary for the development of the plants are also correct and conducted at the right time. Reducing or increasing the water content of the soil causes a change in the leaf temperature. Thermal images can be used to improve the irrigation mode. It is known that the over-irrigation of different fruit crops can reduce the content of sugar and other substances, hence the quality of production. Lower soil moisture content than required may result in a decrease in yield quality and quantity. In conclusion, proper management of the limited water resource is of utmost importance. This contributes to the development of various specific irrigation methods.

When designing any radiometric system, detection is essential. Important parameters are sensitivity, signal noise ratio and visualization based on temperature differences. In order to achieve high accuracy in measurements and visualization, special techniques for recognition, processing, various types of corrections and optimizations are used.

II. Theory

The aim is to establish, record and visualize changes in the surface temperature of the examined bodies. This information is contained in the energy characteristics of their radiation, in the energy characteristics of other sources found in the system and in the characteristics of the distribution medium.

The radiometric approach is suitable for the study of the spread of thermal radiation and its interaction with objects in the distribution area when the preliminary specification of its complete coherence and the absence of the effects of interference and diffraction are not essential for the systems under study.

When we conduct measurements in real situations from the standpoint of physics and mathematics, it is suitable to apply the radiometric approach. The propagation of the thermal radiation is carried out in scattering, absorption and emitting environment. During the establishment of the propagation equation, we have to take into account all influencing factors [7,10,12].

Due to the fact that the point of view is generally not perpendicular to the emitting surface, we will use a dimension representing the surface and angle density of the emitted flux, that is, its radiance [11,12]

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$$L=\left(d^4\Phi\right)/\left(d\,\Omega dA\cos\theta\right)\ . \tag{1}$$

Since we will perform measurements in a precisely defined frequency range, we will use the spectral density of the same magnitude

$$L_\lambda = dL/d\lambda\ . \tag{2}$$

To define the process, we will use the radiation energy output of the elementary flux at a given point from the radiating surface in the half space 2π

$$M=\left(d^2\Phi\right)_{2\pi}/dA\ . \tag{3}$$

As we are interested in a certain part of the wave spectrum, we will use the spectral density of the radiation energy output

$$M_\lambda=\left(d^3\Phi\right)_{2\pi}/\left(dAd\lambda\right). \tag{4}$$

When we need to do research in the infrared spectrum, we always base Planck's law on the emission of a black body.

In nature, the bodies differ in their radiance from that of the black body. This requires the introduction of a correction factor called emissivity coefficient

$$M_\lambda(\lambda,T)=\varepsilon(\lambda,T)M_{black\,b.}(\lambda,T)\ . \tag{5}$$

Let us consider a real radiometric system for temperature measurements. We will monitor the interactions and energy transformations of the radiations with atmosphere located in the volume between the studied object and the radiometer. The set-up is shown in principle in Fig. 1.

In the volume enclosed by the viewing angle towards the radiometer, a radiation from the studied object enters. With such studies, the scattering and absorption in the atmospheric channel are of utmost importance. Also, the thermal radiation of the atmosphere itself is important, as part of this radiation is aimed at the camera and added up to the radiation of the studied object, because their directions coincide. In the volume between the object and the camera, it is also possible for other radiations to enter. These are distributed in different directions. Some of them can come from independent external sources, others could be the result of multiple scattering of the aerosol particles and the molecules of the different gases. Generally, when we describe the energy interactions within a system, we should take into account all influencing factors and the expression will be the following

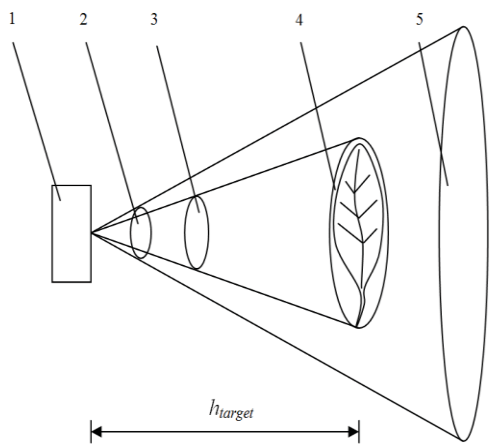

Fig. 1. General set-up of a plant leaf radiometric investigation 1-radiometric device; 2-solid view angle of the radiometric device; 3-solid view angle of the plant leaf investigated; 4-essential area of the plant leaf surface which produces radiation (target); 5-radiation from the atmosphere, h_{target} - distance to the target

$$\begin{aligned} dL_\lambda/dz = &-\left(\alpha^{(s)}+\alpha^{(a)}\right)L_\lambda+\alpha^{(a)}L_{\lambda,black\,b.}+ \\ &+\left(\alpha^{(s)}/4\pi\right)\int_{4\pi}L_\lambda^{'}P_A d\,\Omega^{'}\quad , \end{aligned} \tag{7}$$

where $\alpha^{(s)}$ is a scattering coefficient of atmosphere, $\alpha^{(a)}$ is an absorption coefficient of atmosphere, and the last addend of the formula

$$\left(\alpha^{(s)}/4\pi\right)\int_{4\pi}L_\lambda^{';}P_A d\,\Omega^{';}\ , \tag{8}$$

shows the scattering by other sources. In our case, the distance from the object to the camera is ignorably small and the neighbouring volumes have the same temperature, therefore this ingredient does not exert any practical impact and can be removed [11,12]. Due to the earlier clarification that the distance from the studied object to the radiometer is small enough, which creates homogeneity of the atmospheric channel, apart from using one particular wavelength within the spectrum (8-12μm), we also assume that the source of radiation is isotropic, as a result of all these conditions, we can assume that the coefficients of atmospheric scattering and absorption are constant in relation to the space and spectrum. In order to perform a numerical calculation of the flux entering the radiometer aperture, we need to solve the following expression

$$\begin{aligned} \Phi_r = {} & A_r\Omega_r\tau_r\left(\varepsilon_t\exp\left(-\left(\alpha^{(s)}+\alpha^{(a)}\right)Z\right)\right)F\left(T_t,\lambda_1,\lambda_2\right)+ \\ & +A_r\Omega_r\tau_r\left(\alpha^{(a)}/\left(\alpha^{(s)}+\alpha^{(a)}\right)\right)\left(1-\exp\left(-\left(\alpha^{(s)}+\alpha^{(a)}\right)Z\right)\right)F\left(T_t,\lambda_1,\lambda_2\right) \end{aligned}$$

(9)

where Ar is the area of the receiving part of the antenna, Ωr is the spatial angle of view. The last multiplier in the two addends is the value obtained after the integration of the spectral radiance of a black body at a given temperature in the range of *λ1* to *λ2*.

We can see that the flow is formed by two main components, the radiation from the object and the radiation from the atmosphere.

III. NUMERICAL INVESTIGATION

The aim is to establish, record and visualize changes in the surface temperature of the examined bodies. This information is contained in the energy characteristics of their radiation, in the energy characteristics of other sources found in the system and in the characteristics of the distribution medium [10,14].

Let us look at a specific example of radiometric investigation for plant leaf, using the theory written above. Spatial viewing angle of the radiometric sensor is fixed. We will see how changing the distance from the radiometric device to the investigated object will affect the heat flows in the system.

For the simulation process we choose the following parameters:

$Ta=295K$, $Tt=293K$, $\lambda 1=8\mu m$, $\lambda 2=12\mu m$, $\varepsilon t=0{,}98$, $\varepsilon_{atm}=0{,}96$, $\alpha^{(s)} = 0{,}03 km^{-1}$, $\alpha^{(a)} = 0{,}4 km^{-1}$, $\Omega_r = 6.10^{-3} sr$, $A_r = 8.10^{-5} m^2$, $\tau_r = 1$

Using Scilab we calculate the values of (9) for different distances [17]. Part of the results are shown in the following Table I.

TABLE I
PART OF SIMULATION DATA

No	*h target*[m]	*Φt* [W],T=293K	*Φa* [W],T=295K
1	0.25	1.40752E-05	1.43632E-09
2	0.5	1.40737E-05	2.87249E-09
3	0.75	1.40722E-05	4.30851E-09
4	1	1.40707E-05	5.74436E-09
5	1.25	1.40692E-05	7.18007E-09
6	1.5	1.40676E-05	8.61562E-09
7	1.75	1.40661E-05	1.0051E-08
8	2	1.40646E-05	1.14863E-08
9	2.25	1.40631E-05	1.29213E-08
10	2.5	1.40616E-05	1.43563E-08

It is very important to compare the flow coming from the target with the flow coming from the atmosphere and how they change with the change of the distance from the camera to the investigated object.

IV. CONCLUSION

Clearly, as the distance in these near-boundaries increases, the flow of the site slowly decreases and the flow from the atmosphere increases smoothly. This is explained by the increase in the radiant volume and shows in practice the increase in the atmospheric channel losses. As the distance increases, the flow of the atmosphere increases much faster than the decrease in the flow from the site but is thousands of times less than it. The linearity in the change in flow values indicates that atmospheric scatter and absorption coefficients are space and spectral constants for the given conditions. At these distances from the radiometric apparatus to the object, the horizontal profiles of the atmospheric scattering and absorption coefficients remain unchanged.

Tracking the proper development of crops requires research to be carried out in their natural environment, in the field or in the greenhouse. This will allow for any deviations that may indicate a problem, to seek the cause immediately and to react as quickly as possible. Recently used infrared thermography remote sensing techniques provide more accurate data for the characterization of plant parameters. They can cover huge areas over a long period of time. The reflectivity of plants depends on the properties of their leaves and their orientation and structure. The amount of energy reflected for a particular wavelength depends on the color of the leaves, their geometry, the composition of the cells and the amount of water in them. These several factors determine the infrared characteristics of the plants. There are big differences and sharp boundaries in these properties. Their study and knowledge makes it possible to improve the methods for remote monitoring and, respectively, to improve the management of plant processes. Technological advances in the manufacture of radiometric detectors give additional impetus to the use of thermography as an indispensable tool in the monitoring, diagnostics and management of plant cultures.

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