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ON ONE METHOD OF DISTANT INFRARED MONITORING

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We present the development results of a new method of aerial (on a helicopter or airplane) infrared (IR) scanning of extensive spaces with the purpose of detecting weak heat sources (fire centers at an early stage of their development) to prevent the occurrence of large-scale forest fires.

The paper presents the description of the IR radiometer as well as the measurement method of point and extended thermal sources with wavelength range of 2.5 to 5.5 microns.

***Keywords*:** infrared sounding, fire sources, forest space, infrared radiometer.

Introduction. The monitoring of environment, the investigation and control of ecological conditions attract a great attention of the mankind, especially at the present stage of development of industry, energetics and urban building. Optoelectronic systems and devices designed for application in ecological studies and in arising extremal situations are always in the center of the scientists' and engineers' attention. In particular, research complexes for early detection of fire sources arising during natural calamities are indispensable. Therefore, the development and creation of infrared devices and systems of thermal monitoring of environment, in particular large forest spaces, is a rather important problem.

The development of modern distant and effective methods of ecological monitoring of large forest spaces is more than actual. In such a situation the only method is remote monitoring from an aircraft (e.g. from a helicopter) while flying over large forests at the altitude up to 1000 *m*.

Brief Technical Description of a Measuring System. Structurally the measuring complex consists of two basic units: an optico-mechanical unit of the IR radiometer and an electronic control unit connected to a personal computer. It is designed to measure spectral radiance and radiation temperature (or it's falls) of point and extended sources of infrared radiation under laboratory and field conditions [1–3]. To automate data acquisition and processing, the spectroradiometer is connected to a computer via a series port RS 232. Optical scheme of the optico-mechanical unit (OMU) is shown in Fig. 1.

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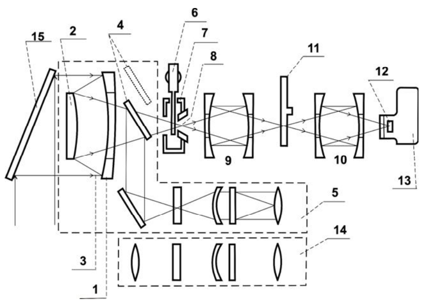

Fig. 1. Optical scheme of OMU.

1 – Primary mirror of the objective; 2 – secondary mirror of the objective; 3 – radiation from an object; 4 – removable plane mirror; 5 – a sight; 6 – a modulator; 7 – a reference cavity; 8 – a field diaphragm; 9, 10 – projection objective; 11 – a disk with interferential light filters; 12 – a sensing site of the photodetector; 13 – a thermos for liquid nitrogen; 14 – a telescope; 15 – a deflection mirror.

The OMU consists of the following main parts:

• Input mirror objective lens of Cassegrain type.

• A telescope for operative pointing to an object under test, equipped with a sighting grid visible through an eyepiece on the OMU back panel.

• Parallax free sight for accurate pointing the spectroradiometer to an area to be measured. The sight has a sighting grid with a cross and a circle, which defines visual field boundaries of the device.

• Projection objective lenses, which serve for refocusing the radiation from a field diaphragm to the plane with light filters and to a sensing site of the photodetector. They represent pairs of spherical mirrors, which are used to avoid achromatic aberrations.

• A block of removable ring wedge variable light filters, which provide a total working spectral range of 0.4 to 14 μm.

• A photodetector, which structurally represents a removable block with a photodetector placed inside it in accordance with the spectral range, a preamplifier and an adjusting mechanism.

Parameter Name	Value
Input objective diameter	180 mm
Focal distance	200 mm
Distances to be focused	from 5 m to ∞
Working spectral range I subband (spectral resolution of 10 %) II subband (spectral resolution of 3 %) III subband (spectral resolution of 8 %)	from 0.4 to 14 μm from 0.4 to 1.1 μm from 2.5 to 5.5 μm from 7.9 to 13.5 μm
Photodetectors: I subband II subband III subband	Si – photodiode InSb – photoresist CdHgTe – photoresist
Field of vision	3 $mrad$
Noise equivalent difference of the radiation temperatures (at 295 K)	0.05 K
Continuous work time	8 hours
Time of preparation to work	15 min
Dimensional size of spectroradiometer: OMU ECU	415 x 278 x 254 mm 500 x 420 x 210 mm
Weight: OMU ECU	not more than 12 kg not more than 15 kg
Climatic conditions of operation: Ambient temperature Atmospheric pressure Air relative humidity	 from $-35\,^{o}C$ to $+45\,^{o}C$ from 84 to 107 kPa (from 630 to 800 mm Hg) up to 98% at $35^{o}C$
Power voltage frequency	(220±22) V (50±1) Hz
Power consumed	not more than 200 W

Full working spectral range of the device is covered with the help of three sets of removable light filters and photodetectors in the subbands of 0.4 to 1.1 μm, 2.5 to 5.5 μm and 8 to 14 μm. Main technical parameters of the device are given in the Table.

During operation the OMU, by means of the wedge guide, is placed on a rotary mechanism, which is fastened to the horizontal platform of a specially prepared tripod.

The electronic control unit (ECU) is structurally of desktop variant. All indication and control elements are mounted on the front panel of the ECU.
Under laboratory conditions the ECU is placed on the table, and under outdoor conditions it can be mounted in a helicopter with the help of dampers.

In brief, the principle of operation of the spectroradiometer consists in the following. Inside the OMU the radiation flow from the test object is collected with the use of an optical system (see Fig. 1) and focused into a sensing site of the photodetector. Further, a preamplifier amplifies an electric signal and transmits it to the ECU. In the ECU the electronic schemes amplify, demodulate and filter the signal from the photodetector output, and as a result of this signal appears at the output, the amplitude of which is a measure of the radiation temperature of the object. Knowing the value of the collected radiation power (from the data of preliminarily conducted energetic calibration of the device), spectral filter features of the system and amplification degree, the output signal can be exactly transformed into an absolute measurement of radiation temperatures of the objects under test.

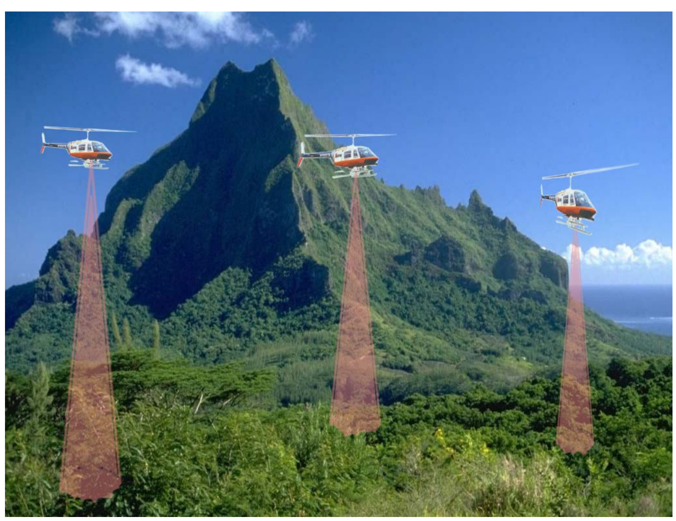

Fig. 2. Helicopter IR scanning of large forests.

We note some advantages of the IR radiometer developed by us [4] compared to the existing close analogs. To widen functional capabilities in the sphere of spectral investigations of thermal objects, besides wideband interferential light filters for spectrum parts of 0.4 to 1.1, 2.5 to 5.5 and 8 to14 μm, the device is also provided with ring readjustable light filters. To eliminate chromatic aberrations, the device optical scheme includes two pairs (see Fig. 1) of mirror projection objectives with light filters and the receiving site of photodetectors in the focuses.

The IR radiometer is mounted in the helicopter and with the help of a deflecting that mirror, by its field of view scans (through the bottom hatch, along the helicopter motion routing) terrestrial surface of large forests (see Fig. 2).

In the presence of fire sources the radiation temperature in that region (within the wavelength range of 2.5 to 5.5 μm) considerably increases and the electronic control unit registers this event. At the helicopter flight altitudes of 200, 500 and 700 *m* the radiometer covers, with its field of vision, surface areas of about 120, 750 and 1500 *sq.m*, correspondingly. With the helicopter speed of 150–200 *km*/*hr* the time of one measurement cycle is 0.1 *s*.

Measurement Technique of IR Flows From Extended and Point Thermal Sources. Before carrying out quantitative measurements of IR radiation emitted by an unknown source, it is necessary to fulfill energetic calibration of the spectro-radiometer, the aim of which is the measurement of the device response to the known standard source (usually a black body with known temperature). By definition, the device calibration means obtaining an electrical signal at the output, which corresponds to a radiation flow unit incident into the radiometer inlet. The calibration is expressed by some function $k(\lambda)$ called spectral calibration characteristic of the device, which includes combined effect of optical elements and electronic amplification of the whole system. $k(\lambda)$ is expressed in *V*/radiation unit with standard level of amplification degree. An output signal of the device is proportional to the difference between the IR radiation flows coming to the photodetector from an external source and from the internal modulated reference black body. During the calibration the radiation from the calibration black body (with known temperature) entirely fills the device field of vision. An output signal $S(\lambda)$ is expressed by the following ratio:

$$S(\lambda)=k(\lambda)\left\{r(\lambda,T)\tau(\lambda,l)-r(\lambda,T_0)+r(\lambda,T_B)\left[1-\tau(\lambda,l)\right]\right\}, \tag{1}$$

where $r(\lambda,T)$ is the Plunk function at the temperature T and the wavelength λ; T is the temperature of the calibration black body; $\tau(\lambda,l)$ is the atmospheric transparency over the path l between the calibration source and device; T_0 is the temperature of the internal reference black body; T_B is the temperature of the air during the experiment.

In the windows of the atmosphere transparency (e.g. for the wavelength range of 2.5 to 5.5 μm), where the transmission is high, $\tau(\lambda,l)$ can be taken to be 1, if the calibration is carried out from the distance l equal to several meters. Therefore, in this approximation for $S(\lambda)$ we can write

$$S(\lambda)=k(\lambda)\left[r(\lambda,T)-r(\lambda,T_0)\right] \tag{2}$$

with the amplification coefficient equal to 1. And in measuring with the amplification coefficient different from 1 the $S(\lambda)$ value decreases by the same factor. The Plunk function value is calculated according to the ratio

$$r(\lambda,T)=\frac{c_1}{\lambda^5}\left[\exp\left(c_2/\lambda T\right)-1\right]^{-1},$$

where $c_1=3.74\times10^4$ $W\,\mu m^4/cm^2$; $c_2=1.438\cdot10^4$ $\mu m\ deg$.

The test objects, the radiation flow of which completely fills the device field of vision, are extent in these measurements. In this case radiance spectral density ($W(\lambda,T)$ $W/cm^2{\cdot}sterad{\cdot}\mu m$) of the object is measured. The ratio (1) can be re-written as

$$S(\lambda)=k(\lambda)\left\{W(\lambda,T)\tau(\lambda,l)-r(\lambda,T_0)+r(\lambda,T_B)\left[1-\tau(\lambda,l)\right]\right\}\beta\ , \tag{3}$$

where $W(\lambda,T)$ is the radiance spectral density of the test object, β is the amplification coefficient of the whole system, and the rest of the symbols are the same as above. The atmosphere transparency $\tau(\lambda,l)$ is either measured simultaneously or calculated with the help of data from literature [5, 6]. From the ratio (3) we can get for $W(\lambda,T)$:

$$W(\lambda,T)=\frac{S(\lambda)/k(\lambda)\beta+r(\lambda,T_0)-r(\lambda,T_B)\left[1-\tau(\lambda,l)\right]}{r(\lambda,l)}\ . \tag{4}$$

Usually the radiation of point sources does not fill the field of vision of the device. If the area A of a radiating object is known, we can measure its spectral radiance according to the above-stated technique, that is

$$W_p(\lambda,T)=W(\lambda,T)\omega\frac{l^2}{A}, \tag{5}$$

where ω is the solid angle of the spectroradiometer's field of vision; $W(\lambda,T)$ is the total spectral radiance measured according to (4); l is the distance from the object under test to the spectroradiometer. While measuring point sources, spectral contrast of a radiation source is also of interest, when the background radiance is comparable to the object radiation. In this case it is necessary to separate the background signal $S_b(\lambda)$ from the signal "source+background" $S(\lambda)$. For the spectral radiation contrast of the source we get the ratio

$$W(\lambda)=\frac{\Delta S(\lambda)\omega l^2}{\beta k(\lambda)\tau(\lambda,l)A}, \tag{6}$$

where $\Delta S(\lambda)=S(\lambda)-S_b(\lambda)$. If A is unknown, we may define the contrast of the spectral luminous intensity of the source (in $W/sterad{\cdot}\mu m$):

$$I(\lambda)=W(\lambda)A=\frac{\Delta S(\lambda)}{\beta k(\lambda)\tau(\lambda,l)}\omega l^2\ . \tag{7}$$

Calculation of the radiation temperatures of the test objects is carried out in accordance with specially developed algorithms and programs.

Conclusion. Application of the given method of remote ecological monitoring of vast forest spaces will undoubtedly bring to the considerable technicaleconomical effectiveness and will also have a great importance in the problem of preventing the fire occurrences, especially of large-scale ones.

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Հեռահար ինֆրակարմիր մոնիտորինգի մի մեթոդի մասին

Բերված են թույլ ջերմային ճառագայթման աղբյուրների (հրդեհի օջախների զարգացման նախնական փուլում) հայտնաբերման նպատակով օդային տարածքների (ուղղաթիռով կամ ինքնաթիռով) ինֆրակարմիր մոնիտորինգի նոր մեթոդի մշակման արդյունքները:

Ներկայացված են ԻԿ ճառագայթաչափի նկարագրությունը, ինչպես նաև 2.5-ից մինչև 5.5 մկմ ալիքային տիրույթում կետային և տարածական ջերմային աղբյուրների չափման մեթոդիկաները:

Р. С. Асатрян, Г. С. Караян, Н. Р. Хачатрян, Л. А. Сукоян.

Об одном методе дистанционного инфракрасного мониторинга

Приводятся результаты разработки нового метода воздушного (на вертолете или самолете) инфракрасного зондирования обширных территорий с целью обнаружения слабых источников теплового излучения (очагов пожара на ранней стадии развития) для предотвращения возникновения крупномасштабных пожаров.

Представлены описание ИК-радиометра, а также методика измерений точечных и протяженных тепловых источников в области длин волн от 2.5 до 5.5 мкм.