OPTIMIZATION OF THE SPECTRAL SENSITIVITY OF AN ATMOSPHERIC REMOTE-SOUNDING SYSTEM WITH OBSERVATION IN THE NEAR UV-RANGE

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It is shown that the optimal — based on the criterion of maximum image SNR — zone of spectral sensitivity of a system for remote sensing of the earth's surface in the near UV region is determined primarily by the magnitude and spectral distribution of the backscattering interference and constitutes 35 nm for normal conditions of observation.

Remote sensing of the earth's surface through the atmosphere is accompanied by significant background illumination, owing to scattering of sunlight into the field of view of the image detector. The existence of an additive background component in the input optical signal reduces the image contrast and the threshold sensitivity of the observation system. In those cases, when the backscattering interference is much brighter than the object, which is especially characteristic for observation in the near UV region of the spectrum (0.3 ... 0.4 μm) and the short-wavelength part of the visible spectrum[1], the recorded signal is observed against a noise background, due to photon fluctuations in the background radiation (when the characteristic noise of the photodetector is insignificant). This operating mode of observation systems is said to be background-limited (BL).

In the BL mode, when the parameters of the atmosphere (transmission and backscattering interference) are functions of the wavelength, the effect of the atmosphere on the optical signal can be likened to that of a spectral light filter inserted into the optical scheme of the observation system[2].

It is thus of interest to optimize the light sensitivity of a remote sounding system with variable optical parameters of the atmosphere by selecting an appropriate spectral range for observations.

We shall study the spectral interval in the near-UV range where the effect of the atmosphere on the characteristics of the signal in passive observation systems is greatest[1].

The photon signal-to-noise ratio (SNR) in the plane of the light-signal transducer of the observation system can be used as a measure of the usefulness of selecting the spectral range in the BL mode:

$$\varphi=\bar{H}_{ob}(\lambda)/(\bar{H}_{ob}(\lambda)+\bar{H}_{thr}(\lambda))^{1/2},\quad H(\lambda)=t_{ac}\bar{S}(\lambda)A \tag{1}$$

where $\bar{H}_{ob,bs}$ is the quantum exposure, T_I is the integration time, S is the average intensity of the optical signal, and A is a coefficient of proportionality, takes takes into account the effect of the optical system on the light field and the spatial parameters of the element of the light-signal transducer.

Transferring to photometric quantities and dropping the constant factor making the assumption that the spectral optical parameters of the system remain unchanged) we can write[3]

$$\varphi=\frac{\int_0^\infty L_{ob}(\lambda)T(\lambda)\tau_f(\lambda)\lambda d\lambda}{\left[\int_0^\infty (L_{ob}(\lambda)T(\lambda)+L_{thr}(\lambda))\tau_f(\lambda)\lambda d\lambda\right]^{1/2}} \tag{2}$$

where $L_{ob}(\lambda)$, $L_{thr}(\lambda)$, and $T(\lambda)$ are the spectral brightness of the object, the spectral brightness of the backscattering noise, and the transmission of the atmosphere, respectively; $\tau_f(\lambda)$ is the spectral transmission of the light filter of the system.

To determine the optimal spectral range we shall employ expressions for the backscattering noise and the attenuated signal from the object obtained in the small-angle approximation of the solution of the equation of radiation transfer in the atmosphere[4]. Because of the complexity of the expressions obtained this problem cannot be solved analytically. To simplify the numerical solution we introduce the following restrictions. Since to a first approximation the spectral filtering properties of the atmosphere are proportional to the scattering coefficients and grow monotonically as the wavelength decreases the long-wavelength limit λ_{max} of the optimal spectral range in the near-UV range may be assumed to be constant and equal to 0.4 μm. It is well known that the optimal (in the sense that the functional (2) is maximum) spectral characteristic of the light filter must have the form of unit triangular function (in the case of additive noise)

$$\tau_f(\lambda)=\mathrm{rect}\left[\frac{\lambda}{\Delta\lambda}\right],\qquad \Delta\lambda=\lambda_{max}-\lambda_{min} \tag{3}$$

which makes it possible to consider only variations of the short-wavelength limit λ_{min} when searching for an extremum.

Using Greens's UV optical parameters of the atmosphere[5] we shall study the magnitude of the input SNR as a function of the limit of the zone of spectral sensitivity of the system. The curves calculated for exoatmospheric observation altitudes with the sun at 50 for the case when the underlying surface consists of freshly fallen snow and vegetation and is observed at the nadir with a meteorological visibility range of 50km are presented in Fig. 1.

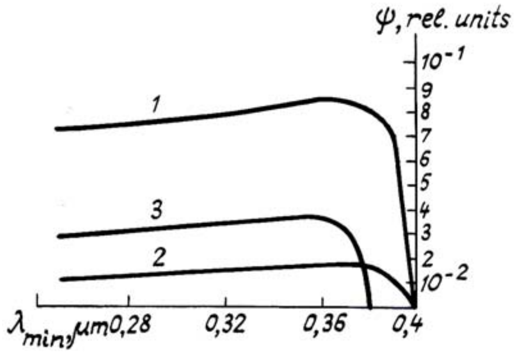

FIG. 1. The SNR versus the short-wavelength limit of the sensitivity zone: 1) λ_{max} = 0.4 μm and the underlying surface is snow covered; 2) λ_{max} = 0.4 μm and the underlying surface is covered with vegetation; 3) λ_{max} = 0.38 μm and the underlying surface is snow covered.

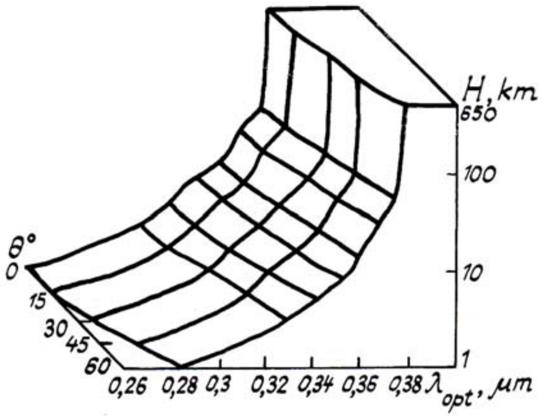

FIG. 2. Altitude and angular dependence of the optimal short-wavelength boundary for a meteorological visibility range of 50 km and a snow-covered underlying surface.

The curves presented illustrate well the existence of a maximum of the input SNR in the UV range, corresponding to the optimal limit λ_{min}^{opt}. It is interesting that the SNR tends to decrease with the spectral range is further enlarged (this is, generally speaking, uncharacteristic for observations in the visible range) and that λ_{min}^{opt} is virtually independent of the reflection coefficient of the object. Thus for weakly reflecting surfaces (vegetation) a relatively insignificant decrease in the optimal spectral range (by 7 nm) compared with a snow covered surface is observed, though the absolute value of the SNR changes by almost a factor of seven. Changing the initial conditions, i.e., reducing the wavelength limit, for example, to λ_{max}, equal to 0.38 μm, shifts the optimal short-wavelength limit by 6 nm. The narrowing of the optimal spectral range when λ_{max} is decreased is due to the sharp increase in the relative fraction of the scattered radiation in the input optical signal. The effect of the change in the relative fraction of the scattered radiation owing to the increase in the optical thickness owing to increased atmospheric turbidity or an increase in the viewing angle or flight altitude is illustrated in Fig. 2, which shows the altitude-angle dependence of the with of the optimal spectral range in near-UV. The effect of the atmosphere becomes appreciable at altitudes above 3 km, and becomes virtually constant at altitudes above 30 km. For viewing angles less than 15° the angular dependence of the optimal spectral range can be neglected.

Analysis of the dependences presented permits drawing some conclusions regarding the optimization of the conditions of observation in the UV range (which also refers to the blue-violet region of the spectrum in corresponding atmospheric-landscape situations).

Taking into account the effect of the atmosphere on data obtained by remote sounding from space shows that the photometric accuracy (inversely proportional to the SNR) of measurements in the short-wavelength channels of multizonal systems can be increased only by increasing the sensitivity of the apparatus (increasing the relative opening of the objective and the sensitivity of the photoelectric transducer), and not by expanding the zone of spectral sensitivity of the system, which under good observational conditions is approximately 35 nm wide.

The variation of the reflection coefficients of natural formations has virtually no effect on the width of the optimal spectral range. The variation of the optical characteristics of the atmosphere along the observation path, however, can significantly affect the width of the optimal spectral range.

For variable observation altitudes it is useful to be able to adapt the spectral zone of sensitivity of the apparatus in order to increase the spectral resolution and contrast of the images formed by the system. This can be done, for example, by inserting a tunable, acoustooptical filter into the input link of the spectral-zonal apparatus[6]; such a link makes it possible to set the spectral sensitivity zone with an accuracy of up to tenths of a nanometer in real time.

REFERENCES

1. V.A. Selivanov and V.P. Budak, Issledovanie zemli iz kosmosa, No. 1, 111 (1988).
2. O.I. Smokii, *Modeling of Radiation Fields in Space Spectrometry,* (Nauka, Leningrad, 1986).
3. J. Goodman, *Statistical Optics*, [in Russian], (Mir, Moscow, 1988).

4. V.P. Budak, E.N. Pestrov and V.A. Selivanov, Tekhnika sredstv svyazi, Ser. Tekhnika televideniya, No. 3, 73 (1987).
5. F.R. Riewe and A.N.S. Green, Appl. Optics, **17**, No. 12, 1923 (1978).
6. V.A. Selivanov, E.N. Pestrov, S.I. Kataev, and G.Ya. Buimistryuk, *Device for Forming a Spectral-Zonal Television Signal*, Inventor's Certificate 1408543 SSSR, N04N7/18, Byull. Izdor., No. 25 (1988).