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Model of noise equivalent temperature difference of infrared systems for finite distance between sensor and object

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Classical noise equivalent temperature difference (NETD) models have been derived under an assumption that the distance between the object and the IR sensor is infinite. The assumption is fulfilled in many industrial conditions when the distance between the tested object and the sensor is many times greater than the focal length of the sensor optics. There are applications, however, where the distance has to be short and the assumption is not fulfilled. Therefore, the typical NETD models found in the literature should not be simply used for infrared systems under such conditions. A new model of the NETD has been derived which enables its value for IR systems under the conditions mentioned above to be calculated. The typical relationship between the values of the NETD determined by means of the classical model and by the new one has been found, and the conclusions are formulated.

1. Introduction

The value of the NETD is usually calculated, according to the classical Ratches model, from the formula [1]:

$$\mathrm{NETD} = \frac{4F^2\sqrt{\Delta f}}{\pi\tau_o\sqrt{A_d}\int\limits_0^\infty D^*_\lambda \dfrac{\partial L_\lambda}{\partial T}d\lambda} \tag{1}$$

where: F – optics number, τ_o – effective optical transmittance, A_d – detector area, Δf – electronics bandpass, D^*_λ – detector detectivity, $\partial L/\partial T$ – derivative of the spectral luminance with the temperature at the radiation wavelength λ and background temperature T.

For the sake of convenience, many assumptions have been made in defining (measuring and deriving relation for) the NETD. Among them, there is an important assumption: the distance between the tested object and the sensor is infinite.

This means that the distance s between object and optics is many times higher than the distance s' between the object image and optics. For such a situation, the distance s' is approximately equal to the focal length of the imaging optics and the optical magnification $\beta \approx 0$ (Fig. 1).

Generally, the NETD defined according to the classical Ratches model (1) is applicable under many industrial conditions when the distance s between the tested object and the sensor s is many times greater than the focal lenght f' of the sensor optics. For a variety of practical purposes, however, the distance has to be short and

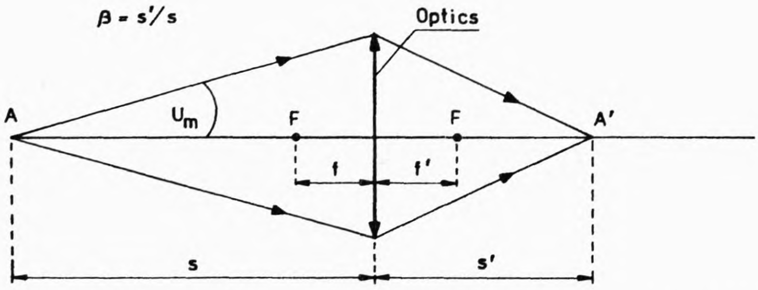

Fig. 1. Optical scheme illustrating the derivation of the new formula for NETD (f' — focal length of the optical system, s — distance between the object A and optical system, s' — distance between the object image A and optics)

the assumption is not fulfilled. Therefore, the typical NETD relations found in the literature cannot be simply applied for infrared systems under such conditions.

2. Derivation of the new formula

The model of the NETD for finite distances between the tested object and the sensor can be derived as follows.

The irradiation in the detector plane can be expressed as [2]

$$E' = \pi\tau_o L_e \frac{\sin^2 U_m}{\beta^2} \quad [\mathrm{W/m^2\,\mu m}] \tag{2}$$

where U_m is the numerical aperture of optical system, β — the magnification, L_e — the object luminance.

The detector is irradiated by the power

$$P'_\lambda = E' A_d = \pi\tau_o A_d L_\lambda \frac{\sin^2 U_m}{\beta^2} \quad [\mathrm{W/\mu m}]. \tag{3}$$

The derivative $\partial P_\lambda / \partial T$ of the power can be written as

$$\frac{\partial P_\lambda}{\partial T} = \pi\tau_o A_d \frac{\sin^2 U_m}{\beta^2} \frac{\partial L_\lambda}{\partial T} \quad [\mathrm{W/\mu m\,K}]. \tag{4}$$

The differential output detector signal is equal to

$$\frac{\partial V_s}{\partial T} = R_\lambda \frac{\partial R_\lambda}{\partial T}. \tag{5}$$

Here R_λ is the detector sensitivity expressed as

$$R_\lambda = \frac{V_N D^*(\lambda)}{\sqrt{A_d \Delta f}}, \tag{6}$$

where $\sqrt{V_N}$ is the value of the noise.

Employing Equation (6), Equation (5) can be written as

$$\frac{\partial V_s}{\partial T} = \frac{\pi\tau_o\sqrt{A_d}\sin^2 U_m V_N D^*(\lambda)(\partial L_\lambda/\partial T)}{\sqrt{\Delta f}\beta^2} \quad [\text{V}/\mu\text{m}]. \tag{7}$$

Equation (7) concerns the signal at a single wavelength. The signal for the whole detector waveband is given by the integral of Eq. (7)

$$\frac{\partial V_s}{\partial T} = \frac{\pi\tau_o\sqrt{A_d}\sin^2 U_m V_N}{\sqrt{\Delta f}\beta^2} \int_0^\infty D^*(\lambda)\frac{\partial L_\lambda}{\partial T}d\lambda. \tag{8}$$

This means that the relationship between the signal and noise at the detector output can be written as

$$\text{SNR} = \frac{\Delta T\pi\tau_o\sqrt{A_d}\sin^2 U_m}{\sqrt{\Delta f}\beta^2} \int_0^\infty D^*(\lambda)\frac{\partial L_\lambda}{\partial T}d\lambda. \tag{9}$$

When SNR is equal to unity, then the temperature difference is equal to the NETD, and we can write

$$\text{NETD}_{\text{NEW}} = \frac{\beta^2\sqrt{\Delta f}}{\pi\tau_o\sqrt{A}\sin^2 u_m \int D^*(\lambda)(\lambda L_\lambda/\partial T)d\lambda}. \tag{10}$$

3. Conclusions

The formula (10) permits us to determine the value of the noise equivalent temperature difference, NETD, of infrared systems in situations when distance between the tested object and the sensor is not too long. The relationship between the NETD_{NEW} calculated according of formula (10) and the $\text{NETD}_{\text{CLASS}}$ calculated according to formula (1) is presented in Fig. 2.

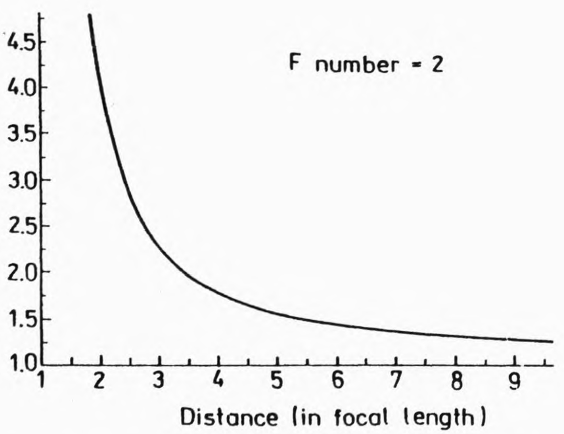

Fig. 2. Typical relationship between the values of NETD calculated according to the classical Ratches formula and the new (Eq. (1)) and Eq. (10))

As can be seen, the temperature resolution of infrared systems even for not too short distances like ten focal lengths is considerably higher (1.24 times) than the NETD calculated according to the classical Ratches formula. It seems that the NETD value should be calculated according to the classical Ratches model when the distance between the sensor and object is at least equal to 10 focal lengths of the imaging optics. The condition mentioned above is usually fulfilled. If not, the temperature resolution should be determined according to derivative formulae.

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