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Experimental determination of the transmission of the atmosphere - based on thermographic measurements

P. Pregowski[1], W. Swiderski[2]

[1]*PIRS - Pregowski Infrared Services, Zachodzacego Slonca 36, 01-495 Warsaw, Poland;* [2] *Millitary Institute of Armament Technology, Prymasa St. Wyszynskiego 7, 05-220 Zielonka / Warsaw, Poland*

Abstract

The influence of limited transmissivity of atmosphere should be taken into account in many applications of IR thermography (IRT). There are a lot of situations when application of computer simulation programs, e.g. based on the LOWTRAN models or using significantly simpler relations, is impossible or limited due to the investigation conditions.

This paper presents one of the procedures to estimate the total influence of the atmospheric path between the object plane and the IR camera. This influence consists of self-emitted and scattered radiation and is often variable, although it cannot be measured or seen directly. We found higher values of signals from the atmosphere than expected. In the case of short wave (SW) cameras, the application of antisolar long wavelength filter reduces the influence of reflected radiation from the sun and also atmospheric signals.

1. Introduction

The main difficulty in correcting the atmospheric influence in IRT results from:

a) direct atmosphere influence on spectral and spatial distribution of signals carrying an expected information from the object;

b) application of broad-band receiving on the basis of selective converters, integrating spectrally the radiation signals, thereby loosing information about their spectral distribution;

c) variability of composition and radiation features of the local atmosphere.
Modelling the spectral features of radiation signals „seen" on the plane of infrared detector, there was stated [1] that:
- *signal generated through the atmosphere can be a very significant contribution to the whole signal and its occurrence can be misinterpreted as a higher transmittance* than it is in reality;
- a significant decrease of such an influence can ensure the limiting of a device spectral band to the range of the most advantageous transmittance in the atmosphere. The spectral contrast coefficient CR_λ was suggested as very effective parameter to find the mentioned ranges.

The following equations (which in various manner include atmospheric influences) can be used to analyse the experimental results:

$$U_m = K \cdot \int_{\lambda_1}^{\lambda_2} [(U_{o,\lambda} + U_{o,refl,\lambda}) \cdot \tau_{a,\lambda} + (1-\tau_{a,\lambda}) \cdot U_{a,\lambda}] \cdot S_{c,\lambda} \cdot d\lambda \tag{1}$$

$$U_m = (U_o + U_{o,refl}) \cdot \tau_a + (1-\tau_a) \cdot U_a \tag{2}$$

$$U_m = U_o \cdot \tau_{a,ef} \tag{3}$$

where:

U_m,U,K,τ_a ,Sc - are the camera output signal, the radiation signal, the design constant, the transmittance coefficient of the atmospheric channel, and the camera spectral characteristic, respectively;

o,λ,refl., a and ef. are subscripts for: object, wavelength (with the limits of λ_1 and λ_2), reemission, atmosphere and „effective", respectively.

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Equation (1) is a basis for the computer modelling for design-optimisation and prognostic needs as well as for much more detailed interpretations of IR measurements.
Equation (2) shows the most popular correction method - used by many manufacturers of thermographic cameras. To determine the transmittance coefficient one often uses a simple function defined from the experiment and simulation, usually on the basis of popular LOWTRAN model. A user can substitute the calculation of „τ_a" by giving the value known from other sources.
Equation (3) represents the methods used as substitute to the previously mentioned methods. In this case „$\tau_{a,ef}$ " represents the total influences of the atmosphere between object and IR camera.

2. Experimental arrangements

The paper [3] presents a method for determination of the correction factor for the total influence of the atmosphere on the basis of the experiment. The measurement of signals emitted from stationary, large enough object with uniform radiant properties were carried out from three distances. It is assumed that the first distance is so short that influences of the atmosphere can be neglected. The aim can be e.g. fast corrections of readings during the changes of a distance between camera and measured object. The results of such measurements are then used to calculate the total influence of atmosphere „$\tau_{a,ef}$ (d_x)" using the following relations:

$$\alpha = \frac{A_2 \cdot \ln(\tau_1) - A_1 \cdot \ln(\tau_2)}{B_2 \cdot A_1 - B_1 \cdot A_2}$$

$$\beta = \frac{\ln(\tau_2) - B_2 \cdot \alpha}{A_2} \tag{4}$$

$$\tau_a = \exp[-\alpha \cdot (\sqrt{d_x} - \sqrt{d_o}) - \beta(d_x - d_o)]$$

where: $A_1 = d_1 - d_o \qquad A_2 = d_2 - d_o$

$$B_1 = \sqrt{d_1} - \sqrt{d_o} \qquad B_2 = \sqrt{d_2} - \sqrt{d_o}$$

and:
d,U - are the distances and amplitude of the received signal for the chosen distance (0,1,2, and „x") between the tested object and camera, respectively.
The function described by this equation is an adaptation of the known relationship commonly used in the 80's (e.g. in AGA 700 cameras family). In the original form this relation can be applied only for strictly defined measuring and meteorological conditions.

During the additional verifications there it was stated as follows:

- value of atmospheric influence, determined according to (4), can be used only for the functions defined by equation (3) (differences exist between calculated „τ_a," based on modelling and „$\tau_{a,ef}$ (d_x)" estimated as the above),
- choice of distances „d_1" and „d_2" to determine this function should fit to required measuring distances „d_x",
- the radiation features of the object which is used to determine the correction data should be very similar to those of the investigated object.

An indirect result of the above mentioned investigations was the determination of signal from the atmosphere between the object and the camera.

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2.1. Determination of the signal generated by atmospheric path : object - IR camera

The tests of self emission from the atmosphere have been recently performed with the set-up shown in Figure1.

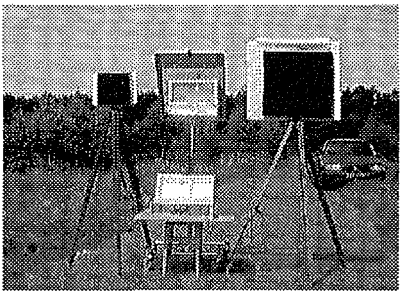
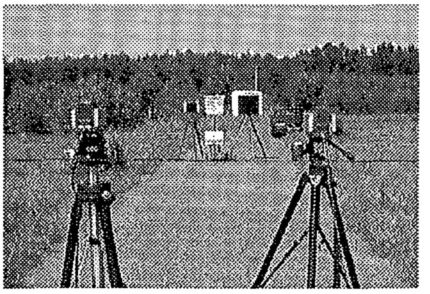

Fig.1

The system of two, large passive black-bodies (honeycomb type with ε>0.99, named as „source A" and „source C") was prepared as standards of temperature near the ambient temperature. There was used also a wooden box (named as „source B“) with a layer of several centimetres of internal foamed polystyrene isolation. On the bottom of the box there was a layer of sand mixed with gravel which was flooded all the time with more than 5 cm of liquid nitrogen (LN2). This way we obtained a large source of radiation signals which were too low to be measurable by the camera. To locate the image of this source between sources „A" and „B“, a high quality large IR mirror was used. For these investigations we used the camera AGEMA 900 (SW and LW types) as well as temperature and air humidity meters. The cameras were moved relatively quickly to the mentioned set of sources. The limited distance signals choice results from the condition of staying within the geometrical resolution of the camera. As the manufacturer does not give the slit response function (SRF) it was estimated by means of „variable size of one bar" method. For the value of 98% transfer of the entrance signals we found that the „elementary field of view" for direct measurement needs about 11 mrad. For the analysis of our results we assumed that signal transfer in the camera and read-outs (which were done according to 12-bit scale of digital processing) can be treated as linear responses to different radiance. All further linear and non-linear corrections and scaling were accomplished according to the camera's instruction and on the basis of this data.

The experiment enabled us additionally to define the coefficient of the atmospheric transmission on the basis of atmosphere influence on transmission of signal differences, according to the relationship:

$$\tau_a(d - d_1) = \frac{U_o(d) - U_a(d)}{U_o(d_1) - U_a(d_1)} \tag{5}$$

where:

d_1 - minimal distance of measured signals (to avoid too low level of signals from source „B“),
U_o (d) - signal received from the „warm" source at a given distance „d",
U_a (d) - signal received from the LN2 source („B") at a given distance „d".
To compare the results of coefficient of transmission in the
atmosphere, obtained from camera's software and obtained from experiment (d_1 > 0) simple correction formula was used:

$$\tau_{a,c}(d - d_1) = \frac{\tau_{a,c}(d)}{\tau_{a,c}(d_1)} \tag{6}$$

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3. Results

The presented investigations were performed at about midday with almost clear sky. The case of SW camera influence with use of typical SRX (antisolar) filter was checked. To express that „what we can see many times is not what we can measure" Figure 2 presents angular dimensions of sources as a function of distance together with the 11mrad camera's limit of correct measurements.

The results of investigated signals (digital units), received at various distances between cameras and objects are presented in Figures 3 and 4. We obtain the following expected and measurable effect: *„As far as the cameras were moved away from the IR source's plane, the signals from the sources „ A" and „C" (having temperatures about 5 - 8 deg. higher than the ambient temperatures due to solar heating) decreased but simultaneously the signal from the source „B" (LN2) was significantly stronger. In the case of LW camera the same phenomena exists although the self-emitted signal was lower".* It is obvious that a similar signal generated in the atmosphere was added during the same time to the signals from all our sources.
The radiance of the atmosphere expressed by $(1-\tau_a)\ L(T_a)$ in equations (1) and (2) is based on the assumption of uniformity and thermodynamic equilibrium of the considered space [2]. Only for such conditions Kirchoff's law is used properly. Especiqally for SW cameras there remains the difficulty to correct for scattering effects which depend on humidity layers near the ground and on the development of clouds during the day.

Figure 5 presents the ratio of signals from "A" and „C" sources to the signals from atmosphere i.e. from the source „B" and efficiency of the antisolar filter application for the decreasing signal from the atmospheric path. Figure 6 illustrates some examples of calculations based on equations (5) and (6). At the present state, because of using only not-stabilised „passive" type IR sources („A" and „C") the presented results cannot be compared.

4. Conclusion

This paper reports results obtained from experiments based on a measuring stand with warm and very cold IR sources. We found much higher values of self-emitted signals from atmosphere than expected. In the ordinary measuring conditions of IRT measurements the extraction of these signals is impossible.
It was shown that in the case of using SW cameras for long range, diurnal, outdoor measurements the application of filters typically used for suppressing solar radiation reflections can reduce „unknown" signals from the atmospheric path between object and IR camera.

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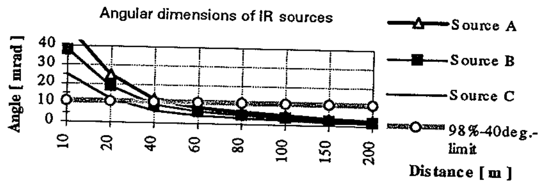

Fig. 2 Limitation of correct readouts caused by changes of the source's angular dimension

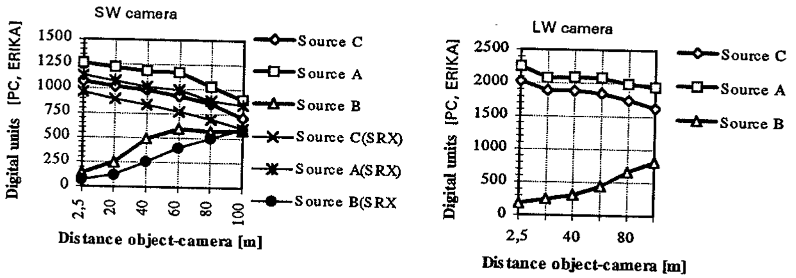

Fig. 3 - Fig. 4 Measured signals from „warm" sources „A", „C" and from the atmosphere (source „B")

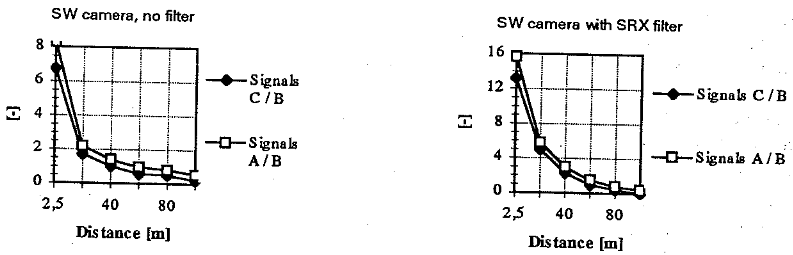

Fig. 5 Influence of the signals from the atmosphere („B") to the signals detected from sources „C" and „A" (temperature of these sources was 5 -8 K above the local temperature of the atmosphere)

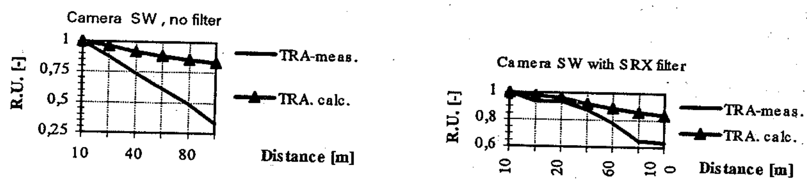

Fig. 6 Coefficients of the atmospheric transmission estimated in accordance with equation (5) for „TRA-meas." curve and equation (6) for „TRA calc." curve (based on experiment and ERIKA program respectively)