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# Estimation of the Sky Radiance

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**For the infrared prefilter model there was a need for testing the sky radiation and defining its fluctuations within the zone of neighborhood area for the current frame and tests of repeatability. It was necessary to do the statistical processing of sky fluctuations in the current frame, because the sky is represented by corresponding layers through which the infrared image prefiltration is done. In this paper the uniformity for low elevation angles has been confirmed. The lower effective temperatures differences exist at large elevation angles**

*Key words*: **infrared, sky, radiation, radiance, temperature, thermal imaging camera, uniformity, contrast, signature, atmosphere, skewness, kurtosis.**

## Introduction

THIS paper deals with the sky radiation in the MWIR (Midwave Infrared) part of the spectrum. This is of a great importance when it comes to monitoring the scene infrared (IR) signature in real time. The most difficult is to obtain reliable information about spatial position of the targets in real time, which depends on the methodology, concept and approach to the problem. In relation to the practical importance, it is possible to obtain a solution, which is cost-effective acceptable model. This refers to a model with unsophisticated modest equipment within the concept of an asymmetric infrared sensor IR system, which should provide a good estimation of the radiation [1-5] of the current background in the immediate vicinity of the observed targets in the space searching process.

Classical triangulation procedures for determining positions mean the involvement of an estimate of objects belonging to a specific area in space, where it is necessary to determine the cross sections of the detected parts of the space in which the object is located. If the image processing operations are used in motion analysis, based on statistical processing and if a new model is set up on the basis of logical operations of sets generally [6], it is possible to pre-process triangulation data and establish much smaller data collections for a process of determining the spatial intersection of detected objects obtained from various image forming devices (triangulation procedure).

### *The characteristics of the sky radiation*

Practical significance has been reflected in the characterization of the spatially and temporally uneven IR signature of pure sky, in order to extract standard targets, spatially distant, in conditions of lower image contrast. This paper does not consider influence of the object (target) radiance but only radiance of the sky as a non-uniform background. Assessing the current radiation of the sky over the value of the contrast threshold (CTV) can be successfully processed using models based on logical operations of sets.

Current radiation of the sky depends largely on the current state in the lowest part of the atmosphere, the troposphere, which contains 80% of the total mass of the Earth's atmosphere. In this layer, at a height of about 5 km, atmospheric pressure is approximately 50% lower than the pressure on the Earth's surface, while up to this height it is 50% of the total mass of the Earth's atmosphere. The troposphere layers up to a height of 100 m are characteristic of the large deviations of temperature and humidity. At altitudes of 100 m to 3 km, in addition to the large deviations in temperature and humidity, there is an increase in wind speed with an increase in altitude. In a free atmosphere, 3 km to 8 km, the temperature and humidity of the air are clearer, while in this layer of air all types of clouds have been formed due to large condensation.

Clouds in atmosphere are formed by condensation and sublimation of water vapor in the free atmosphere and have no repeatable structure. They represent an aerosol, which consists of small liquid droplets, frozen crystals, or other particles suspended in the atmosphere (particles raised from the soil surface). In general, we distinguish two processes: the first, as a result of saturation of the air when it is cooled to its dew point; and the second, when it gains sufficient moisture, usually in form of water vapor, from an adjacent source to raise the dew point to the ambient temperature. There are more classifications of clouds in relation to their shape, way of appearance, physical properties, height of formation and existence. It is characteristic that they do not have reproducible shapes and the same density in individual parts,

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even within the same group. Clouds behave like a good absorber and emitter in the IR part of electromagnetic spectrum, while in the visible part of the spectrum they act as a good diffuse reflector. As such, in relation to the aircraft which lies in front of the cloud, it can contribute to not seeing the parts of the emission surfaces of the aircraft as they will have the same radiance. The contribution of the clouds located behind the aircraft can be such that one part of the emission surfaces of the aircraft is observed to be warmer and the other cooler in relation to the cloud radiance in the vicinity of the aircraft.

From other backgrounds' sources of radiation the effects of radiation from the surface of the Sun and the Moon appear. The background radiation source models, in older papers [7-10], have been derived from the concept of simple uniform background models, which corresponds to:

- Clear sky, or
- Clear sky with the partial cloudiness.

The results of the obtained spectral distributions in mobile spectrographic laboratories, used to determine the IR spectral radiation of sky, confirm the dominance of reflected solar and sky radiation at wavelengths $\lambda \leq 3$ μm, and thermal radiation at wavelengths $\lambda > 3$ μm.

In the remote IR detection of chemical agents [10] in a complex environment, where the requirement is to extract these signatures from harmless substances in the air, different backgrounds' spectra, as spectra of soil, forests and low the sky, on an irregular basis for a period of one year, are also analyzed. Deterministic effects are generally induced through signature of gases, aerosols and variable backgrounds.

In recent papers, different methods of tracking variable-size targets with experimental results [11] indicated an effective suppression of background disturbances. Some methods [12], besides the possibility to detect dim and small infrared targets with small amount of computation, high detection probability, and low false alarm rate, also adapt to various complex backgrounds. There are suggested methods [13] of segmentation of thresholds for detecting targets and suppressing false alarms with better background suppression.

In order to separate the target, for its extremely low energy contrast relative to the immediate background of sky, which is the subject of this paper, additional information on the nature of the pure sky is required.

One way to increase the precision of the set system is sensors selected way, their connection to the system, and the applied method for the acquisition of detected aircraft relative to the current background.

The variability of the characteristics of the aircraft's signature during the flight in the spectral range of the work of the selected sensor depends on the change in its structural parameters (both geometric and emission), relative to the relative position of the observed object of interest and observation point which change, which directly affects the appearance contrast and output vectors of target data for the observation passive optoelectronic systems, since the current background's signature value is spatial-time variable.

After the introductory considerations, the usual treatments for assessing the attenuation in the atmosphere and the contrast of the target against the background of the clean sky have been pointed out. By conventional thermal imaging measurement, an arbitrarily selected sky sample (spatial and temporal) has been observed. The analysis of the results shows the change in the statistical moments of the effective temperatures of the sky according to the change of elevation angle.

## Measuring methodology

*Atmospheric transmission*

The atmosphere is mainly considered in the terms of spectral selectivity and attenuation in relation to the radiation of various sources passing through it. Absorption and scattering are usually represented by a unique parameter of attenuation through the atmosphere:

$$\sigma(\lambda)+\alpha(\lambda)+\gamma(\lambda) \tag{1}$$

where: $\sigma(\lambda)$ is spectral coefficient of attenuation, $\alpha(\lambda)$ is spectral coefficient of absorption and $\gamma(\lambda)$ is spectral coefficient of scattering. Spectral transmission $\tau(\lambda)$ through the atmosphere for the coefficient of attenuation $\sigma(\lambda)$ [km$^{-1}$] and path/distance through the atmosphere $R$ [km] is approximated with:

$$\tau(\lambda)=e^{-\sigma(\lambda)R} \tag{2}$$

Transmission through the atmosphere could have been calculated using different numerical models such as LOWTRAN, MODTRAN, HITRAN, FASCODE, OPAQUE and others. LOWTRAN [14-16] is the most commonly used and quoted for different estimates of parameters in the atmosphere [17].

In order to enable the IR devices to be used successfully in the area of their ultimate performance, in the framework of aviation means and means of air defense, while achieving other tactical advantages, the conditions for their application include a clear sky and a good transmission through the atmosphere [16], so that the background of the clear sky is the basic setting for determining the range of the value of the attenuation coefficient in the atmosphere.

In the literature, for the needs of estimation and impact of attenuation in the atmosphere [14-16], the coefficients of attenuation were used, σ <0.1 km-1 [16], (variations from 0.02 km-1 to 0.08 km-1; under certain conditions, the atmospheric attenuation can be neglected).

In this paper, samples of the pure sky have been examined, as well as parts of the sky, partially covered with clouds. It has been thought that there is no Sun's influence in the daily conditions and the Moon's influence in the night conditions on the target.

Imaging devices provide object (target) detection based on its apparent contrast against neighboring background. The contrast in the image obtained from the radiant exitance from the IR scene can be estimated [17] for a pixel of interest, via the equivalent value of the target exitance $M_T^e$ and target background $M^e_B$ and the real target exitance, $M_T$. Contrast is considered favorable if it is better than 5% for the spectral range from 3μm to 5μm, and better than 7% for the spectral range from 8μm to 14μm.

Thus:

$$M_T^e=\frac{S_T}{S}\cdot\tau_a\cdot M_T+\frac{S_T-S}{S}\cdot M_B^e \tag{3}$$

Respecting contrast:

$$K=\frac{\tau_a\cdot M_T-M_B^e}{\tau_a\cdot M_T+\left(2\frac{S}{S_T}\right)M_B^e} \tag{4}$$

Where:

- $\tau_a$ is transmission of atmosphere,

- $S_T$ is adopted surface of the target expressed in $m^2$, and
- $S$ is surface of current field of view at specified distance in the targets' plane expressed in $m^2$.

*Measurement equipment and measurement set up*

Sky radiance spatial distribution is time dependent and non-uniform. The spatial and temporal changes of the celestial glow within the infrared range of medium wavelengths (MWIR), using changes of the spatial temperature gradient over time have been observed. We selected application of statistical momentums (skewness and kurtosis) [6] as a metrics of the sky radiance changes. Skewness is a measure of asymmetry in a statistical distribution, where the curve appears distorted or skewed either to the left or to the right. Kurtosis is a measure to show how the distribution's tails compare to the normal.

By analyzing the sky scene based on the obtained results from the summer sky measurements with the SC 7200 FLIR thermal measuring camera at a location approximately 45° N and about 22° E longitude (moderate continental climate), before sunset and after sunset, it has been observed that above the elevation angle of 50° (from the upper direction of the horizon), the characteristics of the sky become constants, while the sky below 50° has a property of an exponentially decreasing effective temperature with height of viewing (elevation angle). Fig.1 shows the frames of the sampled sky radiation.

The sky sector has been selected from 8.8° to 44° in height and 11° in width with a temperature window of 5°C to 42°C, the frequency of the image acquisition is 100Hz and the integration time of 699 μs. The two neighboring nature of the sky has been recorded - late afternoon at 19.00 and nightfall before sunset at 20.15 (June 2, 2016). These recordings have been carried out according to the same methodology. The sky has been recorded successively, within the above mentioned sky sector and the stated nature of the sky, in the following way:

1. Statically (camera is not moved during recording - fixed space is observed);
2. The previous scene has been modified by introducing particles of dust of different dimensions to simulate fine-grained disturbances in a scene with a defined preferred direction within the affected field of view, in a various scenarios, at a randomly selected time during the recording period; and
3. Dynamically, uniform movement of the camera in the horizontal direction to the right (viewed in relation to the field of view of the camera) from the eastern position to the southeast continually with the constant rate of 5°/s.

For the recording gathered at 19.00h, it is characteristic the existence of a clear sky, and for the recording at 20.15h, the existence of cloudiness 3/8 with stratus that corresponds to the typical meteorological situation of Serbia's climate on the periphery of the urban environment, according to the European Climate Assessment & Dataset.

Radiance of the clear sky radiation can be represented by parameters of unique emissivity and temperature depending on the angle of elevation of the observation of the sky. The effective temperature is the measure of the total radiance, which determines the radiance of the absolute black body (ABB) of temperature layers of the sky, and the elevation angle is related to the coefficient of attenuation along the atmospheric path and the emissivity of the atmosphere.

Dependence of spectral radiance through the atmosphere by elevation angle decreases uniformly. The areas with low heat radiation are no longer so black in thermal images (The level of black represents the coldest, and the white level the warmest area of IR, the observed IR frame of the thermovision records in the gray level distribution).

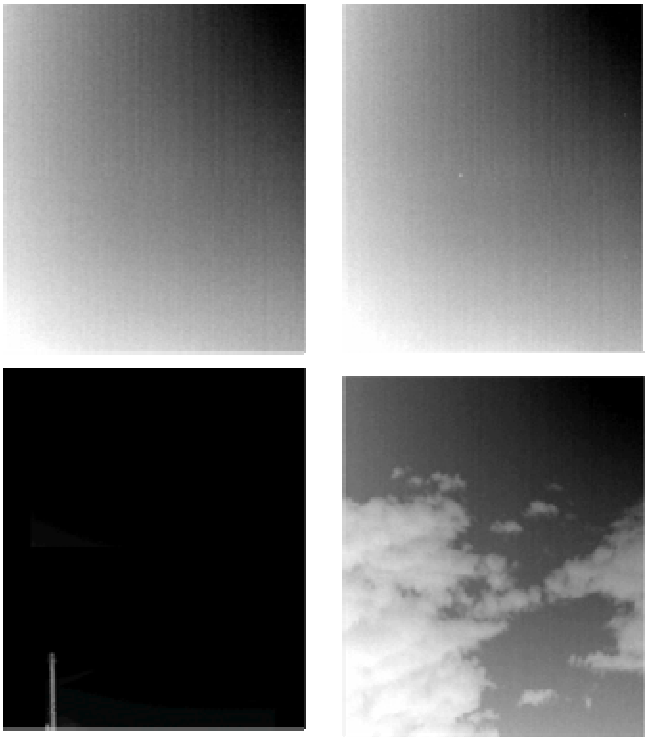

**Figure 1**. Frames of the sampled sky (upper left - part of the IR scene of pure sky, upper right - part of the IR scene of pure sky with artifacts of which several have been artificially inserted , down to the left - part of the IR scene close to the soil (see the part of the chimney pipe), down to the right - part of the IR scene of the sky covered by clouds)

In this process, each spectrum of the background represents a result of total radiation and fluctuations in the background. Low frequency fluctuations in the atmosphere give a spectrum with stable peaks (deterministic), based on which the contents of atmospheric particles and gases can be monitored. The aforementioned process for obtaining the signature relies on short-term and random changes in temperature and optical path, whose nature has not been clarified even today.

## Disccussion

In many applications shown to this day, the background radiance has been evaluated based on its mean effective temperature value [18] and it represents an important parameter for the characterization of the background's scene. Fig.2 shows the measurement and the extrapolation approximated dependence curve of the change in the atmosphere's layers effective temperature with the observation elevation angle of the sky in day conditions (19.00 h, sunset at 20.00), and Fig.3 shows the measurement and the extrapolation approximated dependence curve of the change in the atmosphere's layers effective temperature with the observation elevation angle of the sky in night conditions (20.15 hours) and the stratus cloudiness of 3/8. The statistical parameters of the IR signature of the sky radiation in the MWIR range of spectrum (mean value, standard deviation, skewness and kurtosis) have been analytically obtained for the measured characteristic signatures of the summer sky by the thermal camera SC 7200 FLIR before sunset and after sunset.

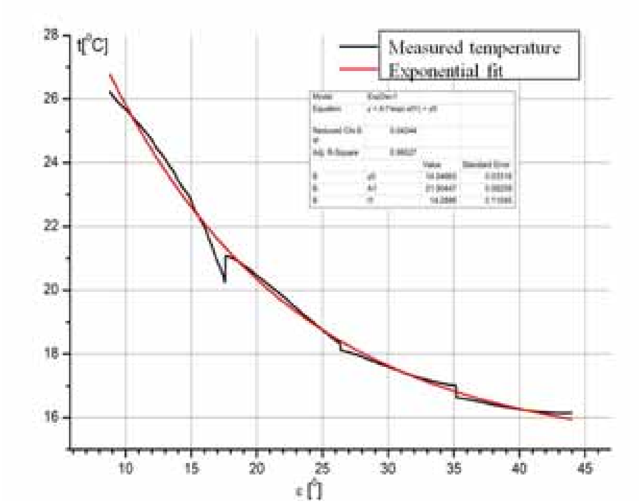


**Figure 2.** Curve of the change in the atmosphere's layers effective temperature with the observation elevation angle of the sky in day conditions

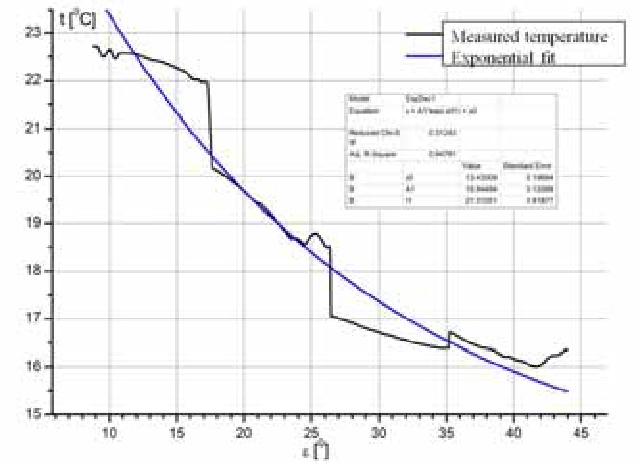


**Figure 3.** Curve of the change in the atmosphere's layers effective temperature with the observation elevation angle of the sky in night conditions

By comparing Figures 2 and 3, it has been noticed that:

- For small angles of elevation (up to 10°), there is a deviation of 8°C to 10°C between day and night conditions.
- At high elevation angles (bigger than 40°), the change is about 0.5°C.
- The same exponential nature of the change in the atmosphere's layers effective temperature with the observation elevation angle of the sky is for both day and night conditions.

Standard deviation of the measured effective temperature, obtained by sky radiance for individual layers of the sky in day/night conditions has been followed by fluctuations of temperatures from 50 mK to 100 mK. The standard deviation slightly increases with the rise of the elevation angle of the observation of the sky, and does not follow the trend of the mean effective temperature values, which decline with the rise of the elevation angle. Distribution of effective temperature fluctuations proved to be stable for large elevation angles:

- Skewness: the graph is slightly moved to the left on the right side of the Gaussian distribution, and
- Kurtosis: a graph is with a relatively flattened distribution, a change from the left.

For small elevation angles:

- Skewness is shifted to the right side of the Gaussian distribution, and
- Kurtosis is significantly protruding (convex) in relation to the curve with Gaussian distribution.

For medium elevation angles (from 10° to 40°):

- Skewness (Fig.4) is shifted to the right side of the Gaussian distribution. The accumulation of a large number of points with a higher effective temperature, and fewer points with lower ones, is for the entire range of the middle angles of elevation, so all the distribution of effective temperature relative to the elevation angle is shifted to the right (the parameters of the inclination of the curve are negative), which has been obtained in the measurement. The heat exchange processes at the low angles of elevation cause a large assimilation of the atmosphere layers close to the soil (at the vertical level are heat exchanges; effective temperature exchange between the soil and the nearest layers of the atmosphere). The large assimilation at large angles of elevation is that heat exchange processes near the high cold sky (effective temperature exchange between the high cold sky and the nearest layers of the atmosphere). The effective temperature exchange processes are temperature-balanced about 19° elevation angle (practically Gaussian distribution).
- Kurtosis (Fig.4) is negative because the distribution is more flattened than the Gaussian.
- Standard deviation (Fig.5) is smaller at the lower angles, because they are more stable effective temperatures and less fluctuations.

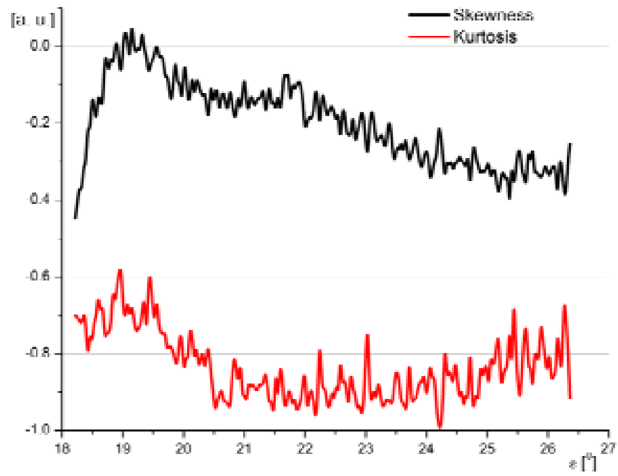


**Figure 4.** Skewness and kurtosis for medium elevation angles

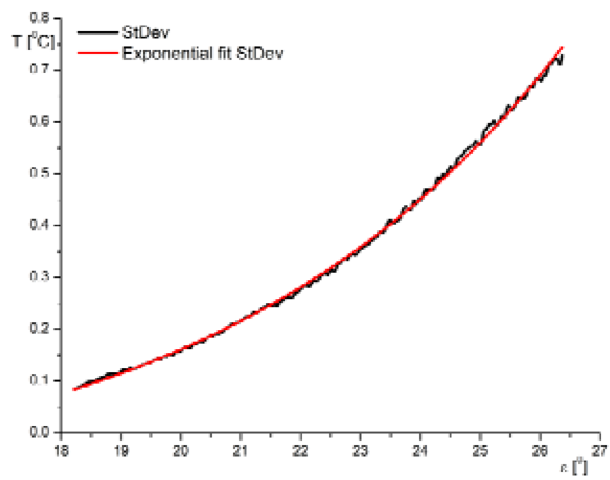


**Figure 5.** Standard deviation for medium elevation angles

## Conclusions

By analyzing the sky scene based on the results obtained by summer sky measurements with the SC 7200 FLIR thermal camera at a location approximately 45°N and about 22°E longitude (moderate continental climate), before and after sunset, it can be concluded that above the angle of elevation of 50° the effective temperature characteristic of the sky becomes constant, while for the sky below 50 ° it has an exponentially decreasing effective temperature with height (elevation) characteristic.

The results confirm that at small elevation angles, there is a good stability and a lower effective temperature difference across the width of the thermal image. There is a slightly smaller contrast in the thermal image at high elevation angles.

Measurements were repeated in daylight conditions during the summer rainy season. Under these circumstances, the transmission of the atmosphere was significantly reduced, so there was no interest in accessing further statistical analysis of data.

This sky analysis is of a great importance for the overlapping tests performed on logical operations of sets for pixels set of detected objects in order to extract false alarms by disjunctive procedures, bearing in mind that this is one of the slowest operations in the detection process in addition to segmentation.

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# Procena trenutne radijanse pozadine neba u pravcu posmatranja

**U okviru modela za pred filtriranje infracrvenih signala, ukazala se potreba za ispitivanjem zračenja neba i definisanje njegovih fluktuacija u okviru zone susedstva za tekući frejm i testove ponovljivosti. Neophodno je bilo da se pristupi statističkoj obradi fluktuacija neba u tekućem frejmu jer se nebo predstavlja u odgovarajućim slojevima kroz koje se vrši predfiltriranje infracrvenih slika. U ovom radu je potvrdena uniformnost za male uglove elevacije i manja efektivna temperaturna razlika po širini slike, dok je kod velikih uglova elevacije nešto manja uniformnost.**

*Ključne reči:* **infracrveno, nebo, zračenje, radijansa, temperatura, termovizijska kamera, neuniformnost, kontrast, signatura, atmosfera, nagnutost raspodele, ispupčenost raspodele.**