AN INVESTIGATION INTO SCATTERING OF OPTICAL RADIATION IN NIGHT VISION APPLICATIONS

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Abstract. This paper presents some aspects regarding the influence of aerosols on radiation propagation from visible and near-infrared domain through atmosphere, using an algorithm for determination of scattering coefficients. Based on this calculation algorithm, the scattering coefficients were determined for several types of aerosols. The investigation shows how the intensity of the radiation from visible and near infrared domains is influenced by the dimension of the attenuating particles, the refractive index, the wavelength of the radiation, and also by the shape of the particles, in case of night vision applications.

Key words: scattering, night vision, optical radiation, aerosols, infrared.

1. INTRODUCTION

In the last years a big progress was made regarding understanding the phenomena that happens into atmosphere and atmospheric physics applications for estimation the performance of night vision systems [1, 2]. This progress was motivated, on the one hand, by continuous development of electro-optics systems [3, 4], even if the performance of these devices is limited by atmospheric conditions, and on the other hand, by the development of high power laser systems and the desire to understand the extreme sensitivity of the laser beam to the propagation through an atmosphere of a certain configuration [5, 6].

Generally, this progress has not led to the development of new physical principles, but rather to the application of physical phenomena known in specific fields.

Absorption and scattering physics is known, but the useful information for application theoretical knowledge is rather limited. Starting from this perspective, the night vision systems trials demonstrated the highly dependence of its performance with the specific atmospheric conditions [6].

The atmosphere is composed of gases and suspended particles at various temperatures and pressures as a function of altitude and azimuth [1, 7–9]. The most important attenuators of electromagnetic radiation are in the troposphere and there are CO₂, clouds, fog and aerosols etc. Water vapor causes a strong attenuation in the lower layers, especially in the coastal and ocean coastal areas [2, 10, 11].
The quantity of water vapor in the atmosphere is expressed by:

- Relative pressure, \( p_{H_2O} \);
- Relative humidity, \( rh \), represents the ration of \( p_{H_2O} \) and saturation pressure of water vapor, \( E_s(T) \) [1]:

\[
rh = \left[ \frac{p_{H_2O}}{E_s(T)} \right] \times 100\%
\]  

(1)

where \( E_s(T) \) is measured in kPa and is calculated using the (with an accuracy of 0.1%) [1]:

\[
E_s(T) = 2.4096 \times \left( \frac{300}{T} \right)^5 \times 10^{\left( \frac{2962}{T} \right)} \text{ [KPa]}
\]  

(2)

where \( T \) is temperature in Kelvin.

- Absolute humidity, \( \alpha \) (g/m³) is defined as [1]:

\[
\alpha = 2170 \times \left( \frac{p_{H_2O}}{T} \right)
\]  

(3)

where the following units are used: \( p_{H_2O} \) is measured in [kPa] and \( T \) is measured in [°K].

Suspended particles vary not only in chemical composition but also in size (from about 0.001 to 10 µm) and shape (spheres, ellipsoids, rod, etc.). There are two categories of particles that have the highest influence on the propagation of electromagnetic radiation through the atmosphere: aerosols and water vapor [1, 2].

The first category of particles, called aerosols, has radius of less than 1 µm. Because these particles are very small, they are suspended in the atmosphere. Scattering by aerosols greatly increases optical attenuation over molecular scattering and is called haze.

The second category of particles, called water vapor, consists of water—dominated particles in the liquid or solid state. These particles are typically larger than 1 µm radius and exist for shorter periods of time than the smaller particles.

### 2. MODELING METHODS

Simulations on the influence of aerosols on radiation propagation from visible and near-infrared domain use an algorithm for determination of scattering coefficients according to the Mie theory on the scattering of electromagnetic radiation caused by aerosols.

Based on this calculation algorithm, the extinction coefficient is determined for several types of aerosols. The dimension of the attenuating particles, the refractive
index, the wavelength of the radiation, and also the shape of the particle and its influence on the radiation intensities in the visible and near infrared spectra were considered.

The visible and middle infrared radiation intensity decreases because of absorption and scattering effects, when the radiation crosses an atmospheric path.

If the attenuating particle situated in the field of view of night vision device (Figure 1) is considered, the radiation intensity that reach the optics of the night vision device, taking into account the scattering effect given by the particle considered, is expressed by the relation [1]:

\[
P_d = I_i \times C_{sca}(r) \times \frac{P(\theta)}{4\pi} \times \Omega_d
\]

where:
- \(I_i\) is incident radiation intensity;
- \(\Omega_d\) is the solid angle;
- \(C_{sca}(r)\) is the scattering coefficient;
- \(P(\theta)\) is the phase function.

If the solid angle is \(\Omega_d \approx \frac{A_d}{R^2}\), where \(A_d\) is the input aperture aria of the night vision system objective, and \(R\) is the atmospherics path length, results captured radiation intensity [1]:

\[
\frac{P_d}{A_d} = \frac{I_d}{A_d} = I_i \times \frac{P(\theta) \times C_{sca}(r)}{4\pi R^2}
\]

![Fig. 1 – Scattering phenomena.](image)

From this point, the solution of incident radiant intensity determination at the night vision device input window is solved if the scattering coefficient \([C_{sca}(r)]\) is determined.

Initial data for simulation are:
- ambient temperature: 5°C;
- spectral domain: 380 nm ...900 nm;
- particle size: 0.5 μm, 1 μm, 5 μm and 10 μm.
The simulation was done for both spherical and non-spherical particles.
3. RESULTS AND DISCUSSIONS

Following the data processing, the relative intensity variation as a function of wavelength, scattering angle, and size of particle is determined.

3.1. CASE OF SPHERICAL PARTICLES

Analyzing the data shown in Figure 2, it is found that scattering is maximum in the propagation direction of the radiation (θ = 0) and decreases with the increase of the wavelength for the same size of the spherical particle. If the radius of the particle increases, the intensity of the scattered radiation increases in the radiation propagation direction and decreases for the other scattering angles.

![Fig. 2 – The variation of the relative intensity with the scattering angle and the radiation wavelength for r = 0.5 μm (left) and r = 1 μm (right).](image)

We could note that scattering decreases with increasing wavelength, the curve allure being identical for particle radius from 1 μm to 10 μm (Figure 3). Radiation in the 800 nm to 900 nm spectrum is the least affected by the scattering phenomenon.

![Fig. 3 – The variation of the relative intensity with the wavelength (left) and the particle radius (right).](image)
For the same wavelength, as the particle radius increases, the intensity of the scattered radiation increases as well. The scattering phenomenon for the spectral range between 400 nm and 900 nm (specific to image intensifier night vision systems) is higher for particle with radius between 1 μm and 5 μm.

3.2. CASE OF NON-SPHERICAL PARTICLES

The non-spherical particle scattering calculation is based on the T-matrix method and the finite-element method. There are two theories that are used for finite element method, namely: volume-based theory and surface-based theory. Since the scattering particle is discretized in volumes, the computation time is rather large, this method is applied to calculate the scattering of the non-spherical particles in the optical domain. The surface meshing method [12] is less used to calculate the scattering caused by non-spherical particles [13–14].

The T-matrix method (or extended boundary conditions) is the most widely used because it is very fast and is based on the assumption that all fields – incident, transmitted and scattered – are made up of series of spherical wave functions. The main advantage of the T-matrix method is that scattering coefficients can be calculated very easily in the sense that the T-matrix or transition matrix depends only on wavelength, particle shape, refractive index, and choice of coordinate system [14–18].

The particle taken into consideration has an irregular shape, arbitrary chosen, as in Figure 4. Its surface was discretized in 16368 triangular surfaces. The calculation program used is SScaTT – Superellipsoid Scattering Tool.

From the analysis of the obtained results, it is found that the variation of the scattered radiation intensity with the scattering angle is much more pronounced
than in spherical particle case, which is understandable given the irregularities presented by the particle under discussion. The other elements of dependence analyzed for the case of the spherical particle are preserved in the case of the irregular shape particle.

![Scattering diagram](image)

**Fig. 5** – Scattering diagram for a non-spherical particle for wavelength 0.5μm (left) and 0.9μm (right).

### 4. CONCLUSIONS

Studying the nature of particles from atmospheric composition allows us to accurately understand and interpret the phenomena that take place inside the atmosphere along the propagation of radiation from visible and infrared domains.

The image quality of the night vision systems is heavily influenced by both the absorption phenomenon and the atmospheric scattering, which depend directly on the shape and size of the particles.

The experimental studies and simulations performed also highlight the dependence of the scattering phenomenon on the particle refraction index, the wavelength and the radiation incidence angle. It was pointed out that the scattering phenomenon for spectral domains ranging between 400 nm and 900 nm (specific to image intensifier night vision systems) is more pronounced in the case of particles with radius between 1 μm and 5 μm.

### REFERENCES
