Holographic method for local atmospheric aerosols statistics

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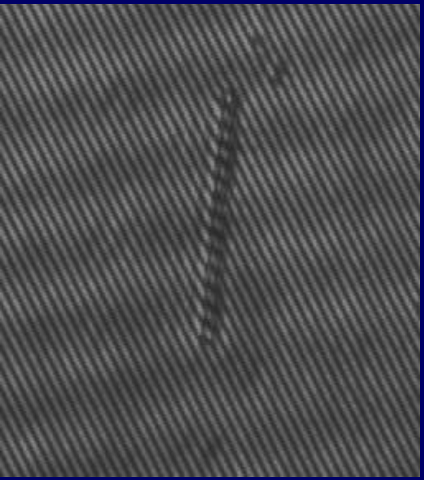
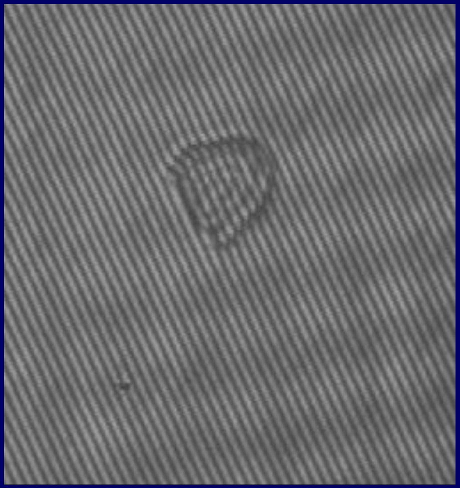
- Atmospheric aerosols physical and chemical properties have a determinant role in LIDAR measurements
- This paper is directed to the laboratory study of individual particles from transparent dry atmospheric aerosols samples
- The particles were collected in a periurban area with a miniature impactor system and filters
- Using DHM(digital holographic microscopy) technique were recorded hundreds of holograms in which every particle is visualized separately
- Our analysis separate four main classes of atmospheric aerosols particles(wires, columns, spherical fragments and irregular)and establish that the predominant class is the first

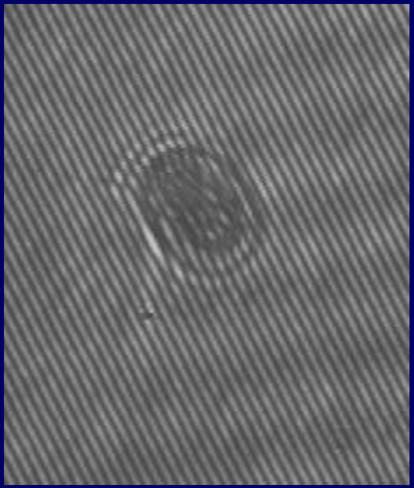
Holograms for transparent atmospheric aerosols from different samples (days) belonging to the four main classes



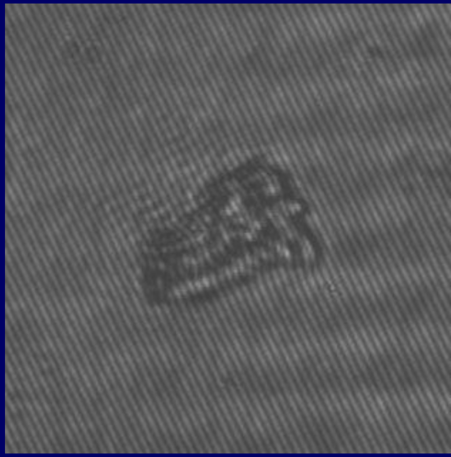
wire



column



spherical fragments



irregular

Conclusions

- The main conclusion is that the first class has organic origin and the last three classes have mineral origin
- The DHM is a cheap alternative method which permits more than visualizing micrometric objects with nanometric details in z direction

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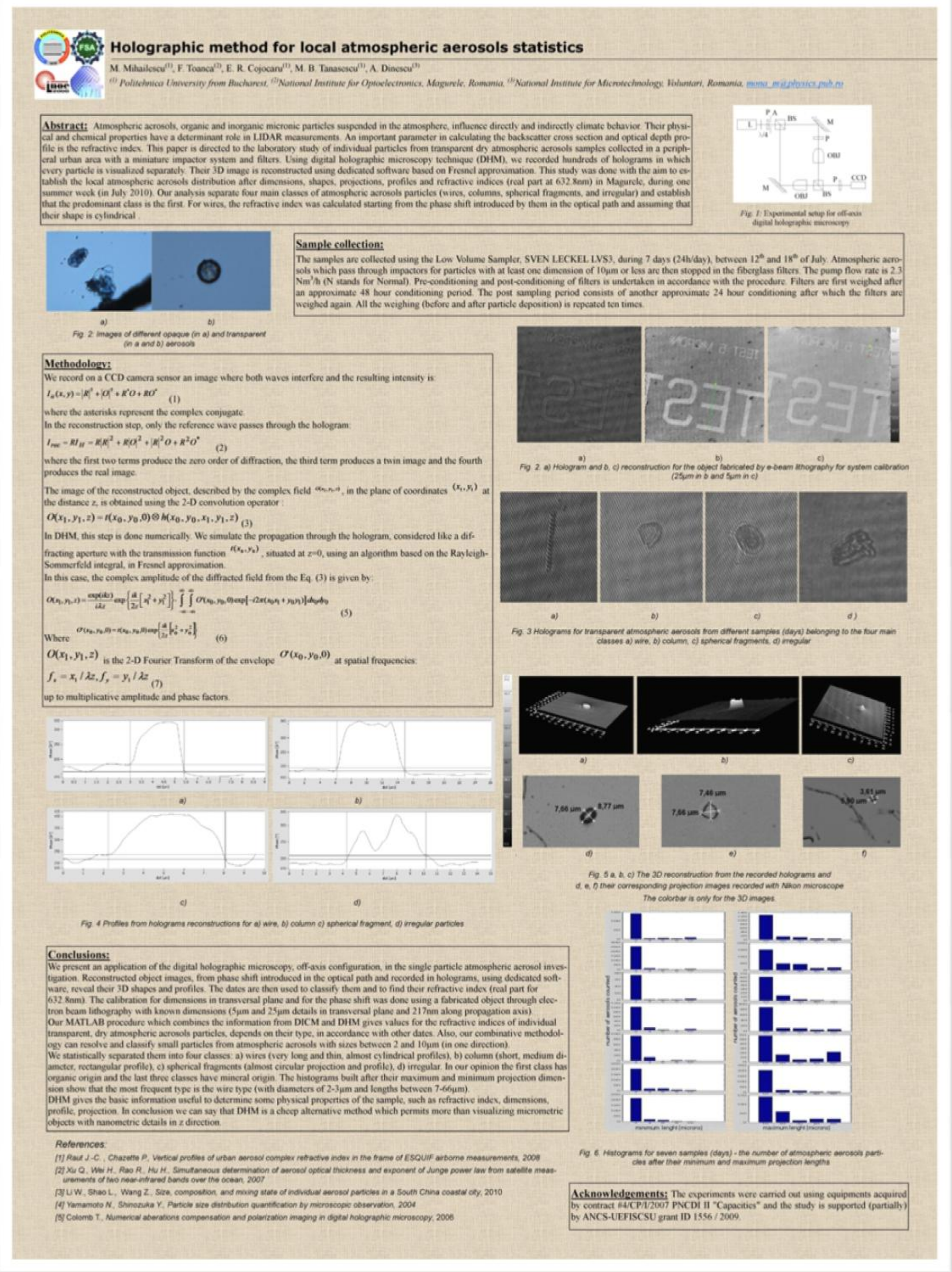

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Abstract: Atmospheric aerosols, organic and inorganic micronic particles suspended in the atmosphere, influence directly and indirectly climate behavior. Their physical and chemical properties have a determinant role in LIDAR measurements. An important parameter in calculating the backscatter cross section and optical depth profile is the refractive index. This paper is directed to the laboratory study of individual particles from transparent dry atmospheric aerosols samples collected in a peripheral urban area with a miniature impactor system and filters. Using digital holographic microscopy technique (DHM), we recorded hundreds of holograms in which every particle is visualized separately. Their 3D image is reconstructed using dedicated software based on Fresnel approximation. This study was done with the aim to establish the local atmospheric aerosols distribution after dimensions, shapes, projections, profiles and refractive indices (real part at 632.8nm) in Magurele, during one summer week (in July 2010). Our analysis separate four main classes of atmospheric aerosols particles (wires, columns, spherical fragments, and irregular) and establish that the predominant class is the first. For wires, the refractive index was calculated starting from the phase shift introduced by them in the optical path and assuming that their shape is cylindrical.

Fig. 1: Experimental setup for off-axis digital holographic microscopy

a) b)

Fig. 2: Images of different opaque (in a) and transparent (in a and b) aerosols

Sample collection:

The samples are collected using the Low Volume Sampler, SVEN LECKEL LVS3, during 7 days (24h/day), between 12th and 18th of July. Atmospheric aerosols which pass through impactors for particles with at least one dimension of 10μm or less are then stopped in the fiberglass filters. The pump flow rate is 2.3 Nm^3/h (N stands for Normal). Pre-conditioning and post-conditioning of filters is undertaken in accordance with the procedure. Filters are first weighed after an approximate 48 hour conditioning period. The post sampling period consists of another approximate 24 hour conditioning after which the filters are weighed again. All the weighing (before and after particle deposition) is repeated ten times.

a) b) c)

Fig. 2. a) Hologram and b, c) reconstruction for the object fabricated by e-beam lithography for system calibration (25μm in b and 5μm in c)

Methodology:

We record on a CCD camera sensor an image where both waves interfere and the resulting intensity is:

$$I_H(x,y) = |R|^2 + |O|^2 + R^*O + RO^* \quad (1)$$

where the asterisks represent the complex conjugate.

In the reconstruction step, only the reference wave passes through the hologram:

$$I_{rec} = RI_H = R|R|^2 + R|O|^2 + |R|^2 O + R^2 O^* \quad (2)$$

where the first two terms produce the zero order of diffraction, the third term produces a twin image and the fourth produces the real image.

The image of the reconstructed object, described by the complex field $O(x_1,y_1,z)$, in the plane of coordinates (x_1,y_1) at the distance z, is obtained using the 2-D convolution operator:

$$O(x_1,y_1,z) = t(x_0,y_0,0) \otimes h(x_0,y_0,x_1,y_1,z) \quad (3)$$

In DHM, this step is done numerically. We simulate the propagation through the hologram, considered like a diffracting aperture with the transmission function $t(x_0,y_0)$, situated at z=0, using an algorithm based on the Rayleigh-Sommerfeld integral, in Fresnel approximation.

In this case, the complex amplitude of the diffracted field from the Eq. (3) is given by:

$$O(x_1,y_1,z) = \frac{\exp(ikz)}{i\lambda z}\exp\left\{\frac{ik}{2z}\left[x_1^2+y_1^2\right]\right\}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} O'(x_0,y_0,0)\exp\left[-i2\pi(x_0 f_x + y_0 f_y)\right]dx_0 dy_0 \quad (5)$$

Where $O'(x_0,y_0,0) = t(x_0,y_0,0)\exp\left\{\frac{ik}{2z}\left[x_0^2+y_0^2\right]\right\}$ (6)

$O(x_1,y_1,z)$ is the 2-D Fourier Transform of the envelope $O'(x_0,y_0,0)$ at spatial frequencies:

$$f_x = x_1/\lambda z, f_y = y_1/\lambda z \quad (7)$$

up to multiplicative amplitude and phase factors.

a) b) c) d)

Fig. 3 Holograms for transparent atmospheric aerosols from different samples (days) belonging to the four main classes a) wire, b) column, c) spherical fragments, d) irregular

a) b) c)

7,66 μm 8,77 μm d)

7,46 μm 7,66 μm e)

3,61 μm 5,90 μm f)

Fig. 5 a, b, c) The 3D reconstruction from the recorded holograms and d, e, f) their corresponding projection images recorded with Nikon microscope. The colorbar is only for the 3D images

a) b) c) d)

Fig. 4 Profiles from holograms reconstructions for a) wire, b) column c) spherical fragment, d) irregular particles

Conclusions:

We present an application of the digital holographic microscopy, off-axis configuration, in the single particle atmospheric aerosol investigation. Reconstructed object images, from phase shift introduced in the optical path and recorded in holograms, using dedicated software, reveal their 3D shapes and profiles. The dates are then used to classify them and to find their refractive index (real part for 632.8nm). The calibration for dimensions in transversal plane and for the phase shift was done using a fabricated object through electron beam lithography with known dimensions (5μm and 25μm details in transversal plane and 217nm along propagation axis).

Our MATLAB procedure which combines the information from DICM and DHM gives values for the refractive indices of individual transparent, dry atmospheric aerosols particles, depends on their type, in accordance with other dates. Also, our combinative methodology can resolve and classify small particles from atmospheric aerosols with sizes between 2 and 10μm (in one direction).

We statistically separated them into four classes: a) wires (very long and thin, almost cylindrical profiles), b) column (short, medium diameter, rectangular profile), c) spherical fragments (almost circular projection and profile), d) irregular. In our opinion the first class has organic origin and the last three classes have mineral origin. The histograms built after their maximum and minimum projection dimension show that the most frequent type is the wire type (with diameters of 2-3μm and lengths between 7-66μm).

DHM gives the basic information useful to determine some physical properties of the sample, such as refractive index, dimensions, profile, projection. In conclusion we can say that DHM is a cheep alternative method which permits more than visualizing micrometric objects with nanometric details in z direction.

minimum lenght (microns) maximum lenght (microns)

Fig. 6. Histograms for seven samples (days) - the number of atmospheric aerosols particles after their minimum and maximum projection lengths

References:

[1] Raut J.-C., Chazette P., Vertical profiles of urban aerosol complex refractive index in the frame of ESQUIF airborne measurements, 2008

[2] Xu Q., Wei H., Rao R., Hu H., Simultaneous determination of aerosol optical thickness and exponent of Junge power law from satellite measurements of two near-infrared bands over the ocean, 2007

[3] Li W., Shao L., Wang Z., Size, composition, and mixing state of individual aerosol particles in a South China coastal city, 2010

[4] Yamamoto N., Shinozuka Y., Particle size distribution quantification by microscopic observation, 2004

[5] Colomb T., Numerical aberations compensation and polarization imaging in digital holographic microscopy, 2006

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