# Registration of the dispersed composition of aerosol media by the holographic method

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**Abstract.** The article describes a device based on the holographic method for measuring the parameters of dispersed aerosols. In the proposed device, the measured particle is irradiated with two beams perpendicular to the main radiation axis, while the resulting holographic image in each of the projections gives an increased amount of information (in contrast to existing solutions) about the parameters of the particles. The information obtained is processed layer by layer using digital holography methods to form a volumetric representation of the aerosol under study, which significantly increases the information content of measurements in comparison with existing devices. Methods and algorithms for layer-by-layer processing of the obtained holographic images are described, which make it possible to reconstruct the parameters of aerosols of complex shapes. The design of the device and an algorithm for layer-by-layer reconstruction of aerosol images are proposed.

## 1 Introduction

The holographic method of recording wave fields makes it possible to record the storage of the entire volume of information about the object of study, namely, the information we need about the size and location of the aerosol particle in space [1-18]. This method provides an opportunity to see the investigated object in separate layers.

For greater efficiency in the study of aerosol particles, an axial hologram recording scheme is used, which is shown in Figure 1 [19]. In contrast to the case of small-angle scattering, it is desirable to use a wide-aperture spatially coherent laser beam for recording a hologram.

## 2 Methods

If the radiation generated by the laser source propagates along the Z axis, then it can be considered a strictly harmonic plane wave of unit intensity, which has constant values of frequency, amplitude, and initial phase. In this case, the radiation scattered by aerosol particles will be described by the function $U$ $(x, y, z)$. Based on this, we will register the intensity in the plane:

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$$I_p(x, y) = |1 + U(x, y, z)|^2 \qquad (1)$$

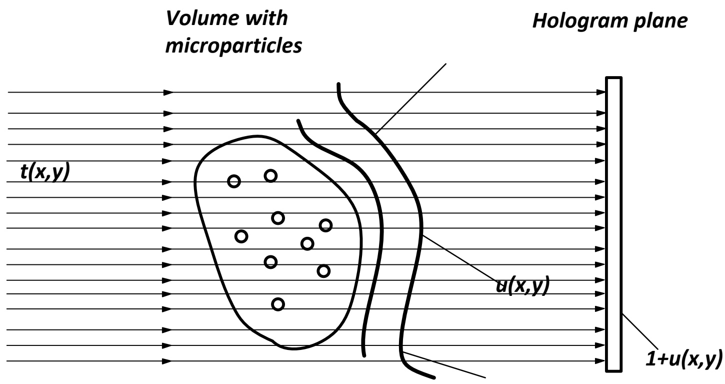


**Fig. 1.** The process of recording a hologram of microparticles

To restore the original picture, let us pass a plane wave through the hologram. The radiation transmitted through the hologram will have a field amplitude distribution according to the expression -$\sqrt{I_p(x, y)}$. It is possible to reconstruct the volumetric picture of the distribution of aerosol particles at a distance z from the hologram, assuming that the wavefront behind the hologram are points of secondary sources:

$$I_0(x_0, y, z_0) = \left|\iint \sqrt{I_p(x, y) exp(ikr) dxdy}\right|^2 \qquad (2)$$

where $r = \sqrt{(x - x_0)^2 + (y - y_0)^2 + z^2}$, $k = \frac{2\pi}{\lambda}$

Changing the "frozen" picture shown in Figure 2, a volumetric cloud of aerosol particles, allows you to obtain the required arrangement of particles along their diameters. The reconstructed real three-dimensional image of the object is the result of plane wave diffraction by the interference structure $I_p(x, y)$ holograms and is described by the function $I_p(x_0, y_0, z_0)$, which can be approximated by a set of cross-sections.

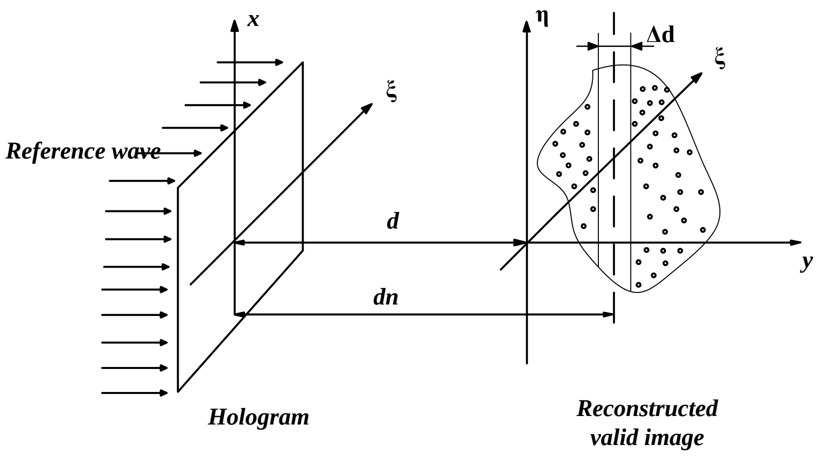


**Fig. 2.** Scheme for reconstructing a real image of an ensemble of microparticles

Considering these quantities as discrete, we will observe a model of this type:

$$P(m,n,d) = \frac{1}{\varphi_n N^2} exp[i\varphi_n(m^2+n^2)] \times$$
$$\times \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} u(k,l) exp\left[\frac{i}{\varphi_n N^2}(k^2+l^2)\right] exp\left[-\frac{2\pi}{N}(km+ln)\right] \quad (3)$$

where $N = \frac{\lambda d}{\Delta\Delta_1}$, $\varphi_n = \frac{\pi d_n}{N^2\Delta^2} = \frac{\pi\Delta_1^2}{\lambda d_n}$, $\Delta$ и $\Delta_1$ – sampling intervals in the plane of the hologram and the plane of the reconstructed section of the object, respectively.

Expression (3) is calculated using special mathematical programs that use FFT algorithms.

## 3 Results and its discussion

Let us consider the practical implementation of a device for holographic analysis of suspended particles [20]. Figure 3 shows a general diagram of a device for implementing a device. The device works as follows. Particles in the measuring volume (region 6) are irradiated by a laser radiation source 1, using prism 2 and objective 3. When passing the measuring volume (region 6), this radiation by the system of objectives 8, 5 and mirrors 9, 4 is rotated and again passed through the measuring volume ( area 6).

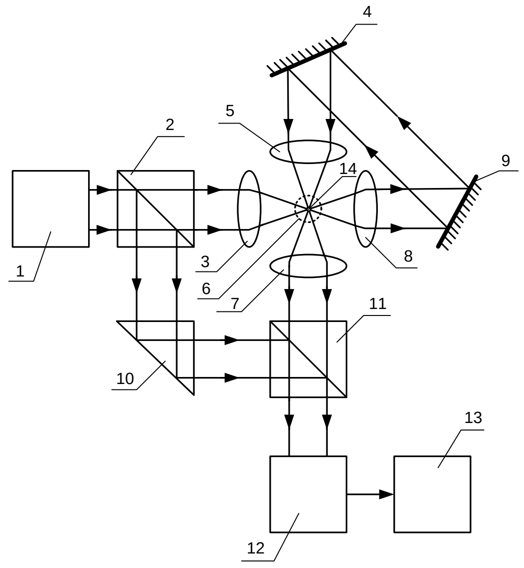


**Fig. 3.** Device for holographic analysis of suspended particles

The specified system for changing the direction of radiation forms a real image of the particle in the measuring volume 6 and it corresponds to the projection of the particle onto a plane perpendicular to the plane of the objectives 3 and 8, since when constructing this image, the particle is illuminated by radiation from the objective 3. The two images obtained in region 6 are transferred by objective 7 into the registration plane. Passing through the beam-splitting mirror 11, this object beam carrying information about two images of the particle in the perpendicular projection planes interferes with the reference beam, which also enters the separation prism 11 through the reflective prism 10. , and in unfolded beams. If the particle is exactly in the common focus of the objectives 8, 5, then the two images will overlap. To eliminate the overlap, it is necessary to separate the focuses in the direction of the measuring volume by an amount higher than the maximum size of the measured particle.

As a result of the operation of the device, two holographic images of each particle are formed in the plane of recording images of the digital video camera 12, which increases the information content of the data for evaluating the shape of non-spherical particles after layer-by-layer processing.

The resulting image of microparticles must be processed in order to classify aerosol particles by their parameters, namely, by size, shape and location in space. The collected information is further used to calculate the specified according to the given algorithm The essence of the algorithm is to transform the original image into a binary (two-level, binary) by using threshold quantization and highlighting the contours of high-intensity areas. These zones are numbered with sequential integers with simultaneous calculation of the particle area and the values of the coordinates of its center of gravity.

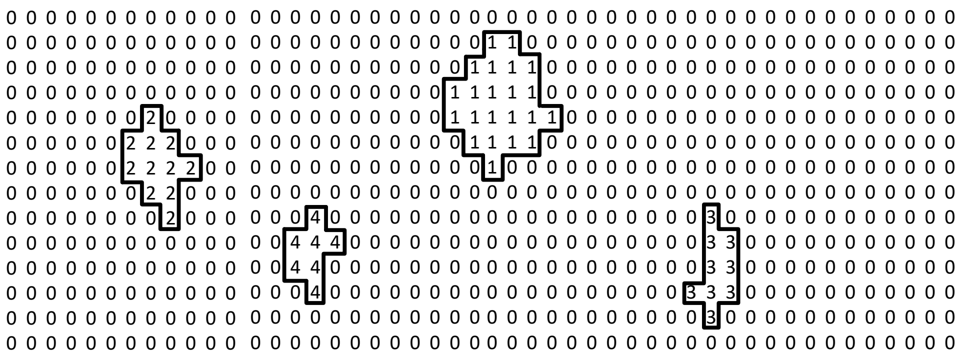


**Fig. 4.** The result of the line-by-line algorithm for classifying particles by size

As a result of this processing, a data array is obtained, which contains information about the area and coordinates of the center of the particle. Figure 4 is an example of how the algorithm works; it clearly shows the final result. This algorithm was tested empirically on microparticles that had a size of about 0.03 mm.

The result of his work is histograms of microparticles in size in each of the cuts under consideration, located 4 cm and 5 cm from the surface of the holographic image.

Thanks to the digital holography used in the device, it becomes possible to record the wavefront of the original object layer by layer by changing the focal length. The block diagram of the algorithm for layer-by-layer recording and restoration of an object is shown in Figure 5. At the end of the layer recording, it is sent to storage and grouping in the memory unit, after which focus control is performed (changing the “d” parameter). By transforming formula (3) into (4), we set the distance d from the radiation source to the first restored section, while this value will change with a step Δd. This will restore the layers sequentially:

$$
\begin{aligned}
&\mathrm{Q}(\xi,\eta,d+\Delta d+j)= \\
&=\mathfrak{I}^{-1}\left\{\mathfrak{I}^{+1}[I(x,y)B(x,y)]\times\mathfrak{I}^{+1}\left[\frac{1}{i\lambda(d+\Delta d+j)}\cdot e^{i\frac{2\pi(d+\Delta d\cdot j)}{\lambda}}e^{\frac{i\pi}{\lambda(d+\Delta d\cdot j)}(\xi^2+\eta^2)}\right]\right\} \qquad (4)
\end{aligned}
$$

By controlling focusing on the elements of the object of study, it is possible to obtain images of the layers of the object at successive focal lengths. Then you can "sew" separate layers into a single object, that is, having the serial number of the layer and understanding its location in space, you can position it in the future in the required plane. After that, the layers in a certain order can be combined and obtained a volumetric hologram of the original object.

When restoring the image at different values of "d" along the axis, it becomes possible to restore the whole object. Figure 6 shows the scheme of layer-by-layer reconstruction of the hologram obtained with the device. It is necessary to perform through lighting while maintaining the axial geometry. This is due to two optical windows that provide this opportunity. The depth of field of view corresponds in order of magnitude to the laser coherence wavelength. It is important to note that the depth of field of view, under certain conditions and assumptions, and regardless of the final resolution, can be equal to several tens of centimeters.

During the verification and measurement stage, the entire system is focused on a specific layer, which is the main one, and images of the remaining layers are built from it. The laser pulses must be synchronized with the expansion of the chamber, as well as the moment the particles are ejected. At the same time, without losing optical quality throughout the entire depth, up to 0.09 m

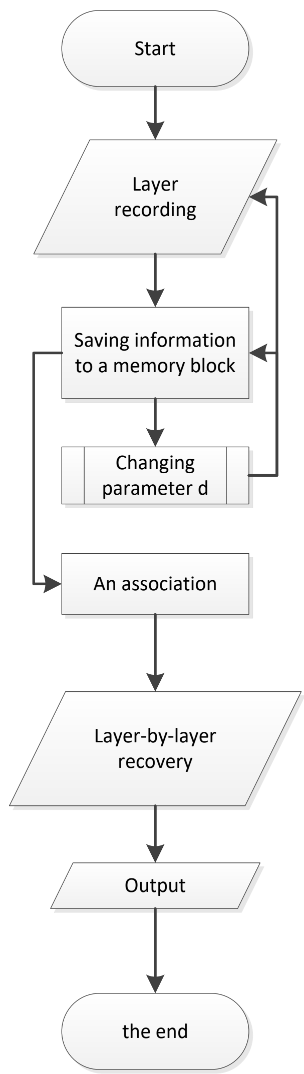


**Fig. 5.** Block - a diagram of the algorithm for layer-by-layer recording and restoration of an object

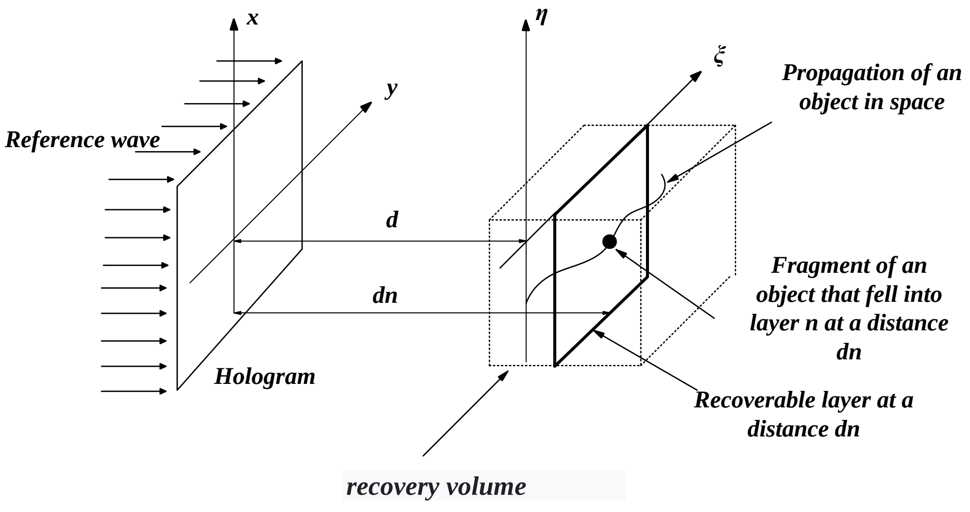


**Fig. 6.** Scheme of layer-by-layer reconstruction of the object's hologram.

## 4 Conclusion

Thus, the considered device, in contrast to the known methods, makes it possible to obtain in the registration plane two holographic images corresponding to its projections onto mutually perpendicular planes, which are reconstructed layer by layer by digital holography methods to form a volumetric representation of the aerosol under study, which significantly increases the information content of measurements compared to existing devices.

## References

1. Guzhov, V. I. Digital holography. Mathematical methods SPb, (2019)
2. Guzhov V. I. Mathematical methods of digital holography. Novosibirsk, (2017)
3. Guzhov V. I. Computer holography: monograph. Novosibirsk, (2018)
4. Koreshev, S.N. Fundamentals of holography and hologram optics SPb., (2009)
5. Bulba A.V. Introduction to digital holography. Petrozavodsk (2009)
6. Andreeva O.V. Applied holography. St. Petersburg (2008)
7. Methods of Computer Optics, (2003)
8. Brazovsky V.V., Evstigneev V.V., Kashkarov G.M., Tubalov N.P. Bulletin of the Tomsk Polytechnic University, **312, 3,** 107-112, (2008)
9. Demin V.V. Izvestiya vuzov. **LVII,. 8-9**, 605, (2014)
10. .U. Schnars, W. Jueptner Digital Holography / Springer-Verlag Berlin Heidelberg. (2005)
11. Ting-Chung Poon Optical scanning holography with Matlab. Springer Science + Business Media, (2007)
12. Asundi A.K. MATLAB for photomechanics a primer. Elsevier Science Ltd. All rights reserved. (2002)
13. M. Paturzo, P. Memmolo, A. Tulino, A. Finizio, and P. Ferraro, Opt. Express **17**, 8709-8718 (2009)

14. P. W. M. Tsang and T.-C. Poon, Chin. Opt. Lett. **11,** 010902 (2013)
15. Kohei Suzuki, Minori Tao, Yuki Maeda, Hirotaka Nakayama, Ren Noguchi, Minoru Oikawa, Yuichiro Mori, Takashi Kakue, Tomoyoshi Shimobaba, Tomoyoshi Ito, and Naoki Takada, Chin. Opt. Lett. **19**, 093301 (2021)
16. Meng Huang, Hongpeng Qin, and Zhuqing Jiang, Appl. Opt. **60**, 4418-4425 (2021)
17. Douglas E. Thornton, Cameron J. Radosevich, Samuel Horst, and Mark F. Spencer, Opt. Express **29**, 9599-9617 (2021)
18. Brad Bazow, Thuc Phan, Thanh Nguyen, Christopher Raub, and George Nehmetallah, Appl. Opt. **60**, A21-A37 (2021)
19. Vodzinsky A.I., Soifer V.A., Khramov A.G. *Investigation of spatial ensembles of particles using the method of numerical holography*, Materials of the 9th All-Union School on Holography. LINP, L., (1977)
20. Semenov V.V. , Atsaturov Yu.G., Khanzhonkov Yu.B., Method for holographic analysis of suspended particles RF Patent No. 2558279, IPC G01N15 / 02, applicant and patentee FGBOU VPO "Don State Technical University" (DSTU) - No. 20141111395/28; declared 03/25/2014; publ. 07/27/2015 Bul. No. 21.