20 YEARS WITHOUT IOSIF NORAIROVICH SISSAKIAN

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Abstract. The report provides an overview of key scientific results of Professor I. N. Sissakian (08.03.1938 – 09.11.1995), and describes the development of the scientific direction "computer optics" after his untimely death.

Keywords: computer optics, diffractive optics, focusator, modan

Citation: Danilov VA, Petrov NI. 20 years without Iosif Norairovich Sissakian. CEUR Workshop Proceedings, 2016; 1638: 236-248. DOI: 10.18287/1613-0073-2016-1638-236-248

Introduction

It's been 20 years since the day of the untimely death of the chief designer Professor Iosif Sissakian of the Central Design Bureau of Unique Instrumentation of the Russian Academy of Sciences (CDB UI RAS) (currently – Scientific technological center of Unique Instrumentation of the Russian Academy of Sciences – STC UI RAS) (March 8, 1938 - November 9, 1995) [1-2]. The report discusses the scientific results of I.N. Sissakian (Fig. 1) in the area of optics and the development of his ideas in our days.

Computer optics

In post-graduate school I.N. Sissakian, along with Eugene L. Feinberg and D.S. Chernavskii, has published a number of theoretical works, based on the development of the hydrodynamical theory of Landau. After defending his thesis, I. N. Sissakian had changed the subject, focusing on optics. Cooperation with the group of Professor V.A. Soifer [3] from the Kuibyshev aviation Institute has led to the emergence of a new scientific field, called "computer optics" [4]. Elements of computer optics were calculated on the basis of solving the inverse problem of diffraction and manufactured by the methods of microelectronics or on CNC machines. I. N. Sissakian organized regular workshops on computer optics. Upon the results of the first (Zvenigorod, 1986) workshop the international collection "Computer Optics" [5] edited by A.M. Prokho-

rov and E.P. Velikhov is started out. Now this is a journal, editor in chief is V.A. Soifer [6].
The first elements of computer optics were the elements for arbitrary transformation of the form of the wave front [7-8]. The Novosibirsk scientists from the Institute of automation and electrometry of SB RAS continue these studies in the laboratory headed by Professor A.G. Poleshchuk. They created the equipment to control the aspherical surface of a multi-meter telescope [9-10]. In 1988 on the initiative of I. N. Sissakian (decision of the Presidium of the USSR Academy of Sciences) the Kuibyshev branch of CDB UI of the USSR Academy of Sciences was established headed by V. A. Soifer (since 1993 – Image Processing Systems Institute of RAS – IPSI RAS [11-12]). In 1992 a team consisting of I. N. Sissakian, V. A. Soifer, V. P. Shorin, V. A. Barvinok, V. I. Bogdanovich, V. I. Mordasov, A. G. Tsidulko was awarded the State prize of Russia for outstanding achievements in science and technology ("for development of laser technologies and their implementation to create new aviation and space technology").

Fig. 1. Professor Iosif Norairovich Sissakian (March 8, 1938 - November 9, 1995)

Under the direction of I. N. Sissakian several PhD and doctoral dissertations were protected in the field of computer optics. In addition to Moscow and Samara, computer optics is developing in Novosibirsk, St. Petersburg, Chernogolovka, Kazan and Penza. A number of his students are now successfully working abroad. I. N. Sissakian supported work of Penza group under the direction of G. I. Greisukh as for the gradient-index, and the diffractive imaging optics [13-14].

Focusators of laser radiation

The first focusators were axisymmetric elements (diffraction axicons), creating coaxis line and the circle [15-16]. Contact of I. N. Sissakian with physicians has led to the formulation of focusing of laser radiation into the cross for the operation of radial keratotomy [17]. Then the task was the synthesis of focusators in an arbitrary curve in the focal plane with a given intensity distribution on the curve. Focusators were created from the visible to millimeter range [18-24]. The problem of focusing in a flat region and a sloped line segments was considered [25-31]. Focusators were investi-

gated theoretically and experimentally [32-41]. New methods for the diffractive microrelief formation were developed to create the focusators [42-51].
In 1989 focusator in a transverse cut with a high intensity distribution at the edges was successfully tested in the US in the Institute "General Motors" for heat strengthening of steel using 3 kW laser of the company "Spectro-physics". Laser technologies with the use of focusators are actively developing [52-53]. The calculation methods were used for focusing surface electromagnetic waves [54-58].

Formation of light beams with remarkable properties

Modans which spatially divide transverse modes of laser beams were created [59-62]. Such optical elements are effective for the analysis of a modal content of radiation propagating in different media as well as for creation of high-sensitive fiber-optics sensors. Thus, in [60], the modans consistent with the Gauss-Laguerre modes were used to determine the modal coefficients in a graded-index waveguide. In [61], the modans with transmission proportional to the superposition of orthogonal Fourier-Bessel functions were proposed to determine the characteristics of aerosol medium. It was shown that the coefficients of the decomposition of scattered light by aerosol particles into the series of Fourier-Bessel functions define the relative concentration of particles or the distribution function of particle sizes. The coefficients of expansion into the series of Bessel functions of different orders define the moments of the distribution function. Moreover, the use of spatial filters, carrying out these transformations, allow the parameters of particles to be directly determined. Investigations in this area are ongoing both with the aim of increasing the sensitivity of fiber-optic sensors [63] and for increasing of transmission capacity and protection of data in optical communication lines [64].
The paper [65] was among the first works in the area of singular optics devoted to the elements forming the beams describing by the Bessel functions. Then a number of elements with unique properties was proposed [66-68]. Optical antennas create the radiation in the form of petals keeping their form and propagation angle at long distances. This made it possible to create lighting devices for various applications [69-74].

Propagation of light in inhomogeneous media

The methods of quantum theory (quantum field theory, quantum statistics, quantum mechanics) were proposed by I.N. Sisakian to solve the tasks of propagation of radiation in inhomogeneous media. In particularly, the coherent states and integrals of motion methods were used for description of propagation of light beams in longitudinally inhomogeneous graded-index waveguides [75-76]. This allowed us to investigate the physics of wave processes both in optical waveguides and natural waveguide channels [77-79]. The quantum-mechanical methods of coherent states allowing the calculation of the average values with the help of operator approach were used to investigate the evolution of the parameters of light beams. The whole dynamics of the system is transferred to the operators in this approach. This allows us to investigate the evolution of the characteristics of the propagating beam with the help of pure algebraic procedure, that is without using explicit expressions for field wavefunctions and without the calculation of any integrals. Coherent states correspond to the wave beams localized in the neighbourhood of the geometrical ray. Such states allow us to introduce in natural way the term of the width of geometrical ray and clearly trace the connection between the wave and geometrical descriptions. The concept of choice of quantum-mechanical formalism in the theory of waveguides is the following. As was shown in [75], the Maxwell equations for the scalar wave paraxial beams may be reduced with high accuracy to a parabolic-type equation. This approximation allows us to apply well developed quantum-mechanical methods to study wave propagation in inhomogeneous media, since the parabolic equation formally is quite similar to the Schrodinger equation in quantum mechanics for a particle moving in a potential well with the parameters depending on time. Only some corresponding redefinitions of parameters need to be carried out. The time plays the role of the longitudinal coordinate and, instead of the Planck constant we have the free-space wavelength. The potential is determined by the refractive index of the medium. The close connection between wave mechanics of particles and optics of light beams has been discussed in detail by many workers. The efficiency of the application of the coherent states representation and density matrix in the tasks of propagation of partially-coherent radiation in inhomogeneous media was shown by I.N. Sisakian and his followers [80-82]. The behaviour of spatial coherence of optical fields in the media with general-square-index and arbitrary regular longitudinal inhomogeneity was investigated. The analytical expressions for the parameters describing the spatial coherency of fields in such media, in particular, for the correlation radius and the width of partially-coherent beam were obtained. It was shown, that the coherent properties of light can be controlled with the help of variation of the laws of longitudinal inhomogeneity. Quantum-theoretical methods were applied also for investigation of the effects of nonparaxiality [83-87] and depolarization [88-90] of radiation in graded-index media. In [85] the nonparaxial focusing of wave beams in a graded-index medium was studied. The minimum dimensions limited by the nonparaxial effects of the wave-beam focusing area were determined. These effects lead to a significant change in the transverse distribution of the light intensity in the focusing area and to an asymmetric distribution of the field intensity in the longitudinal direction. In [87] the remote focusing of light in a graded-index medium via mode interference is demonstrated using exact analytical solutions of the wave equation. Strong focusing of a light beam occurs at extremely long distances and this repeats periodically with distance. High efficiency transfer of a strongly focused subwavelength spot through optical waveguide over large distances takes place with a period of revival. Results obtained may be of great importance in biology and medicine, optical recording and microscopy, and could be exploited in various applications such as novel endoscopes, sensors and imaging systems. In [88-90] the polarization effects at the propagation of light in a multimode graded-index optical fiber are considered using the method of coherent states. In [91-94] these methods were used for consideration of the effects of spin-orbit interaction of light in optical waveguides with a cylindrical symmetry. Propagation of polarized vortex light beams in a rotationally symmetric graded-index optical waveguide is investigated by solving analytically the three-component field Maxwell’s equations. An operator approach to calculate the average values describing the propagating beams is developed. In [94] the influence of polarization (spin) and orbital angular momentum on the characteristics of spiral (vortex) light beams at the propagation in a graded-index fiber is studied.

Automation of scientific research

I.N. Sissakian paid great attention to the development of information technologies and automation of scientific research, as well as to optical instrumentation. The second edition of the international proceedings "Computer optics" prepared by him for printing was entirely devoted to the problems of automation of scientific research [95]. He raised and organized the solution of tasks of computing [96-97] and optical [98-103] experiments, paid significant attention to the development of asymptotic methods in computer optics [104-105]. In all of these areas the studies are being carried out to the present time [106-111]. Works in the field of optical instrumentation are continuing in the STC UI RAS and IPSI RAS. For example, the development of hyperspectrometers: on the basis of acousto-optics – in STC UI RAS [112], and on the basis of spectral filters and diffractive optical elements – in IPSI RAS [113-116].

Conclusion

Practical implementation of elements of computer optics in modern digital cameras demanded the suppression of spectral and angular dependences of their diffraction efficiency. Various aspects of this task were presented, in particular, in the works [117-119]. The results obtained allowed us to define the conditions under which the high image quality (and, in particular, the lack of a halo) can be achieved using the elements in an optical system with single-layer or double-layer relief-phase microstructure.

Methods of computer optics are used for creation of new elements for the control of light [120], and technologies of manufacturing of holographic gratings [121]. In [120] a high-efficiency subwavelength diffractive beam combiner operating in a visible spectral range is designed, fabricated, and demonstrated. Such a device combines red, green, and blue color beams into one output light beam. Diffraction efficiencies of different types of gratings are calculated for various materials, incidence angles, and polarizations of light. It is shown that the plasmon resonance via a grating coupling occurs at the determined conditions. Subwavelength gratings with a period of 400 nm are fabricated and tested using laser and laser diode sources. This type of color combiner can be useful in many application areas, such as picoprojectors, where efficiency and compact size are crucial. It was shown that such gratings have a high efficiency and can significantly reduce the size of the projection devices used in mobile phones, etc.

Modern computational and technological capabilities allow colleagues and students of I. N. Sissakian to transfer from the tasks of diffractive optics to the problems of diffractive nanophotonics [122-131].

These results open up the prospects of solving one of the main tasks of computer optics – implementation of optical calculations [124-127] and lay the intellectual foundations of advanced information technologies [131].

Finally, we mention two practical applications of computer optics elements: protective holograms [132-133] and optical filters for professional and amateur photography [134].

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