Book Reviews

Interferometry by holography

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Ed. by David L. MacAdam

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Since some time the Springer-Verlag keeps editing a series of English translations of valuable Russian books on optics. The book reviewed belongs to this series. This time, the three-year period of time that elapsed since the original Russian edition became available seems to be short enough not to outdate any part of the book.

What is the concept of this book? When looking through it it is evident that the book offers a wide introduction to holographic interferometry aimed at wide circle of readers of different background in optics. In accordance with this, both the language and the mathematics employed are relatively simple. Also the clear argumentation used in the book as well as its logical structure make the content available also to the specialists in other fields. Especially, the first part *General Principles* may allow the less advanced readers to be quickly acquainted with the fundamentals of optical holographic interferometry.

The exposition of subject matter begins in the first Chapter with an explanation of light interference principles and concepts (including, among others, the principle of superposition, concepts of coherence and contrast) important in interferometric techniques. Here, the argumentation is rather intuitive and nicely illustrated with simple diagrams, while the mathematical formalism is reduced to the reasonable minimum. In the next section, totally devoted to optical interferometry, the discussion starts with giving a classification of optical interferometers, and is next continued separately for each of the two fundamental types of interferometers, i.e., the twin-wave interferometers. (with wavefront and amplitude division) and multi-wave interferometers. Also some applications in methodology (measurement of displacements or wavelength), spectroscopy (Fourier spectroscopy, high-resolution spectroscopy) and other techniques (antireflection coatings) are briefly indicated. The next topic – holography – starts with the explanation of the basic concepts illustrated by the respective equations for the recording and reconstruction stages, respectively. The detailed classification of holograms, due to the way of forming the object and reference waves and to recording the interference pattern, helps to clarify the further discussion of their basic properties. Next, the real-time and double-exposure methods are widely discussed.

The basic part of the book starts with discussion of experimental techniques including light sources, recording materials and typical experimental setups. This is followed by some mention of vibration-damping supports and more important setup elements like: pinhole diaphragms, collimators, beam-splitters, light scattering screens and hologram fasteners.

The next three Chapters devoted

to investigations of phase inhomogeneities, displacements and reliefs, and. finally, holographic studies of vibrations are typical fields of holographic interferometry applications. To be more specific, the first type of examinations is there represented by a review of basic problems or techniques, like those of visualization of phase inhomogeneities, relations between the spatial distribution of the refractive index and the quantity being measured, localization of interference patterns, the methods of calculation of the spatial distribution of refractive index from interferograms and the like. This is followed by an analysis of the sensitivity problem in different types of holographic interferometry. Two interesting applications of holographic interferometry to holographic diagnostics of plasma and to gas- dynamic investigations excellently illustrate the capabilities of holography in these fields.

The possibilities of interferometric holography in measurements of the displacements and reliefs are discussed in the last but one Chapter. Here the mechanism of formation of interference-patterns bearing information about the displacements and the methods of interpreting the respective holographic interferograms are explained in general terms, the considerations being more specified for the case of multi-hologram and single-hologram methods discussed thereafter. Next, the three basic methods of relief investigation, i.e., two-wavelength methods, immersion method and double-source-methods are briefly described. The Chapter ends with some comments to flaw detection by holographic interferometry, richly illustrated by respective interferograms.

In the last Chapter the holographic methods of studying the vibration process are reviewed. The study starts with evaluating the influence of the object displacement on the brightness of the reconstructed image for the cases of motion with constant velocity, stepwise motion, and harmonic vibration. Next, the principles of strobo-holographic method are explained and illustrated with examplified setup schemes. These are followed by a short discussion of large-amplitude and small-amplitude vibrations examination and an even shorter mention of phase determination of the object vibration.

As it may be easily seen from the above, the book offers a comprehensive and to some extent complete course in "classical" holographic interferometry, including its principles, basic methodology, more important measuring setups and their optical elements, and the like, supplemented by some necessary information about the light sources and recording materials. This is, however, not the feature that would distinguish this book among so many others in the field. The more characteristic seems to be the clear and simple way of lecturing, the logic structure of the presented material, well fitted mathematical formalism and well-chosen graphical and photographic illustration. This is simply a nice book and will certainly be both useful and enjoyable to all holographic interferometrists, especially to those beginning to specialize in this beautiful field. Also the more advanced students of optics, physics or metrology may certainly read the major part of the text without essential difficulties. Finally, the book may be recommended to enginneers of almost all possible specializations interested in using a precise (although sometimes difficult to handle) technique of nondestructive testing.

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The Computer in Optical Research Methods and Applications

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This book is a survey of fundamental mathematical tools used experimentally in contemporary optics. One of the distinguishing tasks of todays research in physics is to ask about the values, i. e. to look for quantitative estimation of the examined effects (in addition to their traditional qualitative description). Hence, an increasing demand for mathematical and especially numerical methods in physical investigations. The book reviewed is certainly intended to meet these requirements to the extent defined by basic needs in selected fields of modern optics (such as optical diffraction, statistical optics, lens design, optical astronomy, optical data processing, computer-generated holograms and the like).

To be more specific, the first Chapter (written by B.R. FRIEDEN), bearing an introductory character, reviews the applicability of computer methods and procedures in different domains of optics. In this context the successes and drawbacks are occassionally mentioned to give the less advanced readers an idea of real possibilities of the respective computer techniques. Therefore, this Chapter may be recommended (as it is usually the case) to the beginners rather than advanced researchers. Independently, kind of guidance to the other Chapters of the book is here also offered.

The second Chapter (written by R. BARAKAT) devoted to *The Calculation of Integrals Encountered in Optical Diffraction Theory* may be of importance to all interested in modern computational methods not necessarily oriented toward the optical diffraction problems. The author, being well known for his many contributions in theoretical optics, begins with a historical example of an evaluation of Fresnel integral. Then he describes some useful procedures, such as trapezoid and Simpson rules, and Romberg and Gauss quadratures. In the context of finite Fourier integral evaluation the original and modified Filon procedures are presented. Further, the method of Euler transformation of alternating series is described and examplified by computation of Hankel transform. At the end of this Section some asymptotic formulae are given. In the next Section the diffraction integrals employed in incoherent imaging are discussed, taking account of the concepts of point spread function, optical transfer function, cumulative point spread function (total illuminance), and the formulae for some typical extended objects. The problem of quadrature is mentioned in the last but one Section in the context of Fast Fourier Transform. The last part of this Chapter is devoted to the sampling expansions which are presented for some very important functions, like transfer function, point spread function, edge spread function, cumulative spread function, and the relative structural content (being the Linfott's image quality). It seems that the high level of the above presentation should provide an interesting reading to anyone interested in optics. The extended and well choosen bibliography, provided after each Section and commented upon in the text, increases the pleasure of studying.

An extensive study in *Computational Methods of Probability and Statistics* is offered in the third Chapter (written again by B.R. FRIEDEN). This is a very systematic and comprehensive review of basic concepts and methods of probability and statistics, oriented so as to meet the demands of contemporary optics, illustrated at a very early stage of considerations by well-chosen examples. The last ideá will be certainly welcome by the readers of beginning interest in both the fields of optics and probability. As the discussion becomes more advanced the illustrative examples are also more complex and important, to become locally the main subject of considerations. This is the case in Sections 3.4–3.7 devoted respectively to illustrations of probability methods and applied to: photographic emulsions and formation of optical images (Section 3.4), description of atmospheric turbulences (Section 3.5), and laser speckling (Sections 3.6 and 3.7). Some statistical methods being selected to meet the needs of special problems in optics are subject to discussion in the next Sections. Also, here the lecture is clear and well illustrated. In this respect the Section 3.15 dealing with estimation of object scene by using maximum entropy and with speckle phenomenon may be especially noticed.

The fourth Chapter (written by A.K. RIGLER and R.J. PEGIS) is devoted to *Optimization Methods in Optics*. The optimization techniques can be applied to a wide range of problems in optics. The authors give, in only 58 pages, a conscise but sufficiently complete introduction to the problems of optimization methods. There are four Sections in this Chapter which present diversified aspects of optimization problems in optics, a review of optimization techniques developed parallelly, by optical designers and by mathematiciens, a number of optimization algorithms available to the designer and examples of solution to some of the typical problems. In details the authors describe the formulation of optimization problems from the curve fitting, thin film filter design, and the design in imaging and illumination systems. Then the authors go through remarks on the historical development, from Newton through the early computer time till nowadays.

Next, the problem of mathematical programming is formulated and classified in very general terms. A few presented algorithms for nonlinear optimization have been based upon a mathematical classification of the methods and types of optical problems to be solved. The following methods are mentioned: first and second derivative methods, descent methods without the use of derivatives and the method for location (estimation) the minimum of a one-variable unimodal function.

A special attention is payed to techniques for constrained problems. The presented penalty and barrier methods are illustrated by numerical examples. The authors gave in detail the algorithm of gradient projection methods, especially good for linear constraints. An extensive description of algorithm for minimizing nonlinear function subject to nonlinear constraints based on geometrical programming is illustrated by solving optical prototype design. This Chapter contains a big ammount of information in fairly conscise form. Hence, frequent recourse to the references may be necessary. Therefore, an extensive bibliography of 117 works from about 1930 to 1978 has been cited. The authors use the language most common to mathematiciens, but they also point out the variations that have been developed by the optical designers. The authors hope that the mathematically inclined reader will find in optics a source of various practically interesting problems to solve and that the optics-oriented person may be motivated to a much deeper study of the mathematical tools available to the reviewers.

The mutual relationship between the computer and optical astronomy is the subject of the fifth Chapter (written by L. MERTZ). This is essentially a modern survey of wide range of computer applications in the observational optical astronomy. A historical introduction provides an interesting comparison between the first ancient astronomical calculations and the possibilities of contemporary electronic computers. Next, the author describes the basic applications of computers in telescopic observations and indicates wide applicability of computers to automation of optical observations and to processing of photometric data. Here, the correction of atmospheric effects, description of variable brightness triple and pulsing stars and their Fourier transforms are discussed. The processing methods used in spectroscopic data handling are conscisely dealt with, while the main emphasis is put on the synthetic improvement of spectrum quality, spectrometer automation, Fourier spectroscopy and phase correction. The last part deals with the computer applications to image processing. Here, the synthetic densitometry, high-pass filtering and speckling interferometry are considered. The principles of Knox-Thompson algorithm useful in mean phase determination, the temporal algorithm working at very low light levels (of order of few thousands of photons per second) and the methods of image improvement and optimizing the average logarithmic atmospheric turbulency are discussed in the Section devoted to speckle imaging. In spite of the discouraging declaration of the author that the presentation is somehow restricted to the domain of his own scientific interest, the review of the problems discussed is really broad and addressed to all interested in observational astronomy.

The last Chapter of this book deals with computer-generated holograms, giving an ordered review of the actual state-of--affairs in this field. In the introduction the mathematical fundamentals of synthetic recording of optical information in computer-generated holograms are given for both cell-oriented and point-oriented holograms. These two types of holograms are next discussed in more details. In the case of cell-oriented holograms the special attention is payed to referenceless on-axis complex holograms (ROACH), of-axis graytone holograms and off-axis binary holograms (known in the literature also as the Lohmann-type or Lee-type holograms), as well as to typical difficulties connected with cell overlapping and gaps when two apertures in one cell and holograms bleacking are used. Also, the point-oriented holograms in their many variants have been presented in an interesting and comprehensive way. The ways of discretisation of the continuous Fourier spectrum and the effect of the random phase coding (diffusers) of the object to be recorded on the obtained image quality and the possibility to influence the image quality by using the suitably chosen phase runs (deterministic diffusers) for the definite recorded object are considered. Five main sources of distribution are named and discussed as far as their influence on the image quality is concerned.

The image generation problems for cases of three dimensional, colour and special images are considered shortly but in a interesting way. Among others, the images generated from the radiotelescopic data and synthetic volumen and polarization holograms are mentioned and their development prospects outlined. The application of the synthetic holography to the coherent and incoherent matched filtering and to symbol recognition are indicated. Some attention is payed to the hardware restrictions on attainable space-band-width product of CGH.

Due to the reviewing character of this Chapter the author refers often to the widely cited literature concering the actually discussed problems, which is important to those readers, who would like to deepen their knowledge in the respective fields of synthetic holography and may be especially useful for the students and researchers specializing in optics, as well as for those working in optical display system.

Summing up, there is no doubt that the book is very valuable both due to its well selected content and its excellent presentation and will be enjoyed by the workers involved in many fields of contemporary optics.

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Inverse Scattering Problems in Optics

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Ed. H. P. Baltes with Contributors

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The 20th volumen of the known Springer-Verlag series Topics in Current Physics, being devoted to a wide variety of *Inverse Scattering Problems in Optics,* is a continuation of the discussion presented in the 9th volumen entitled the *Inverse Source Problems in Optics* and initiated also by P.H. Baltes in 1978.

This time the text has been elaborated by 15 contributors who wrote 7 papers six of which deal with new problems or fields from the realm of inverse optical problem in the most cases not mentioned in the previous book. The first Chapter of this book presents a short review of the literature positions, which appeared in the meantime, dealing with a wide variety of inverse problems starting with geophysics and ending with the theory of elementary particles. A particular attention is here payed to the following problems: uniqueness of reconstruction, scattering surface structure estimation and the phase problem. The difficult and incompletely solved problem of Lambertian type scatterer construction is considered more carefuly than the others, and, in particular, the so far achieved partial and approximated solutions are reported. The discussion indicates that it is not sure whether the solution ever exists.

The authors (G. Ross, M.A. Fiddy, M. Nieto-Vesperinas of the second Chapter entitled *The Inverse Scattering Problems in Structural Determinations,* discuss first the philosophical background of the inverse problem. Starting with the viewpoint of epistemology they consider the basic difficulties appearing each time when any inverse problem is formulated. The importance and specificity of these difficulties may be illustrated by the following example: In the electromagnetism the direct problem of diffraction has been formulated in the form a of complete mathematical theory. However, its experimental verification requires the solution of the inverse problem (which is a secondary problem with respect to the direct one). Next, the authors discuss the direct scattering problem for continuous scatterer model giving the quasi-monochromatic solution of the Maxwell equations. The following considerations have been restricted to the one-dimensional case, i.e., to that of two-dimensional Maxwell equations. Here, the properties of the entire functions describing the scattered field are exploited especially extensively. However, the *Theorem 2* (an analogon of the Paley-Wiener theorem) given on page 30 seems to be doubtful, may be due to its unclear formulation. In this Chapter it has been pointed out that the deterministic inverse problem is reduced to the determination of the location of complex amplitude zeros in the scattered field. However, the knowledge of the zeros is (as it is well known) available when the phase information, which is lost during square-law detection, is known. Therefore, the authors come to conclusion that the solution of the inverse scattering problem is determined by solution of the phase problem. The authors discuss their earlier idea of interpreting zeros as the information carriers, which may be attributed to the Gabor concept of communication chanels or tubes of information, as well as to different concepts of degrees of freedom. This interesting idea has, so far, no analogon for the three dimensional amplitudes. In the second shorter part of the Chapter 2 the possibilities of applying the theory of entire functions to the statistical inverse scattering problem are examined. There, the analytic properties of the spectral density autocovariance function are considered for the case of isotropic medium. The examples of the spectral density functions, which are not entire functions, are given. The difficulties connected with the examination of the properties of the spectral density matrix elements describing the heterogeneous medium are signalled.

The development of the photon-counting techniques initiated by the known Hanbury-Brown-Twiss experiment widens their application in examination of the statistical properties of the optical fields. The authors (E. Jakeman and P.N. Pusey) of the third Chapter devoted to *Photon-Counting Statistics of Optical Scintillation* describe the application of these techniques to investigation of strong scatterers evoking strong intensity fluctuations, i.e., the scintillations. In this case the photon-counting technique is unavoidable, since it enables to determine the high order correlations necessary to describe such fields. The inverse problem splits into two separate problems, i.e., the inverse detection problem and the scattering problem. In the first part of the Chapter 3 the instrumental effects, like time and space averaging, dead time detector, which make the inverse procedures very complex, are considered on the base of the semiclassical formulation. In spite of these difficulties (dependent on the noise) the photon-counting technique is reliable and accurate enough to serve as an excellent measuring tool providing the data necessary to design and verify new models in the theory of scattering. In the second part, the discrete models of strong scatterers employing the K distributions are discussed. Finally, the experimental aspects of the problem are illustrated by some examples of dynamic scattering in nematic liquid crystal, hot air phase screen and the extended atmospheric turbulence.

The Chapter 4 (*Microscopic Models of Photodetection*) written by A. Selloni is an extension and continuation of the Chapter 3. All the features of the real detectors distinguishing the latters from an ideal detector are indicated. These are: final sizes, final measurement time, final number of samples, noises, and so on. The quantum detection theory, i.e., the open-system detection theory presented in this Chapter enables to consider the above mentioned factors without any ad hoc assumptions, as it is the case in the semiclassical theory. The author of this Chapter, being simultaneously one of the co-creators of this theory, presents it in terms of advanced formalism of the quantum mechanics, which requires a deep mathematical background. In this context the idea to present-concise results and formulae describing the properties of different optical fields at the end of the Chapter seems to be very helpful. The description of the theory of open systems ends this Chapter.

Each numerical procedure used to solve the given inverse problem (apart from the existence of the solution) must be stable. The solution should depend in a continuous way upon the input data, since otherwise the noises may generate arbitrarily high errors in the solution. These problems are discussed by M. Bertero, C. De Mol and G.A. Viano in Chapter 5 entitled *The Stability of Inverse Problems*. Ill-posedness of the inverse problems (for instance, the integral equations) is well known. The only way which permits to avoid this problem is to restrict the class of solutions by admitting the additional a priori information. If these restrictions may be described by linear operators the procedure is given by the theory of regularization due to Tikhonov and Miller. The authors describe precisely the mathematical basis of this theory giving (as its result) the general formulae for solving both the deterministic and statistical aspects of the problems.

The methods of reconstruction error estimation may be also found. Next, the application of this theory to some important inverse problems in optics has been indicated. The following problems have been discussed: perfect lowpass filtering and bandwidth extrapolation by means of prolate spheroidal wave functions, inverse diffraction problem from far-field data, inverse scattering problem for perfectly conducting bodies, inverse scattering problem in the Born approximation, an object reconstruction from projections and the Abel equation. The procedure to be used when the operators describing the reconstruction are nonlinear, which is, for instance, the case in phase problems, is unknown. The methods used in such cases have not been mentioned.

The method of reconstruction from projections is one of the earlier measuring reconstruction techniques. This method is used in interferometry, radioastronomy and its application to medical X-ray tomography was a commercial success. In the Chapter 6 entitled *Combustion Diagnostics by Multiangular Absorption* the authors (R. Goulard and P.J. Emmerman) discuss its applicability in the combustion diagnostics. First, the methods of solving the fundamental integral equation appearing in the problem of reconstruction from projection (Radon transform) have been discussed, though the discussion is there restricted to algorithms solving the equations, the whole mathematical aspects of the problem, i.e., the existence, uniqueness and stability of the solution being neglected. The multiangular scanning was not used, yet, in the absorption experiments, except for the "onion peeling" method which, as it was shown by one of the authors (R. Goulard) of this work, cumulates the experimental errors. The algorithms basing on Fast Fourier Transform, the so-called convolution method (CM), and the algorithm reduced to solution of large systems of linear equations, the so-called algebraic reconstruction technique (ART), which were successfully used in interferometry and tomography, seem (due to the authors of this Chapter) to be useful also in combustion diagnostics. Considering the process dynamics a good reconstruction of the absorption coefficients is possible when the measurement is carried out sufficiently quick. Therefore, the authors emphasize the reduction of the number of measurement angles. In this respect the ART manifests some supremacy, while CM is suitable for application of simple noise smoothing techniques and is much quicker. Several demonstrative simulations have been made by using the CM algorithm for fields of Gaussian type. Finally, the experimental aspects have been considered.

In contrast to the first six Chapters the last one *Polarization Utilization in Electromagnetic Inverse Scattering*, written by W.-M. Boerner deals with macroscopic description of inverse electromagnetic scattering problem. Monstrous difficulties both of practical and theoretical nature are connected with this problem. In radar target imaging problem the scattered and incident fields are essentially vector fields, since the scatterer changes the polarization of the incident wave. The present development of the theory and technology in broadband antenna enables the simultaneous measurement of amplifiers, phases, Doppler type information and the components of polarization scattering matrix. The author considers the possibility of exploiting this opportunity. At the beginning he widely discusses the fundamentals of the theory, i.e., the vector diffraction integrals, polarization, polarizations scattering matrix and the Mueller scattering matrix. Next, the way of choosing the optimal polarization state is shown on the basis of polarization scattering matrix. In the review of different inverse theories the physical optics applications are represented most extensively. After taking account of such effects, like polarization, target conductivity, bistatic scattering and multiple reflection, the physical optics may constitute a basis for the development of electromagnetic inverse scattering theory. Also the usefulness of vector holography has been indicated. However, a further development of radar target shape reconstruction is still restricted by the lack of a self-consistent vector theory.

As it may be easily seen from above, the inverse problems are here discussed in numerous variants and from different viewpoints. Such a treatment must involve relatively many contributors. This, in turn, creates obvious difficulties as far as stylistic and structural uniformity is concerned. Fortunately, this time these difficulties have been successfully overcome. There are almost no fragments which would be repeated in any two Chapters (except for the *Introduction* to the Chapter 3 which contains unavoidably some common elements with the Chapter 4. The mathematical formalism is very versatile, being each time well fitted to the specificity of the problems considered. This creates certain difficulties to the readers specializing only in selected aspects of the inverse problem, and wanting to be acquainted with the others. On the other hand, the numerous references given after each Chapter and additionally listed at the end of the book (this time with the titles) offer an opportunity to widen or deepen the knowledge on particular problems.

In summing, this book will certainly be useful for advanced researchers working on any aspects of the inverse scattering problems. It may be also welcome by beginners, since it offers them the possibility of quicker and more complete entering into the domain of the inverse problem in its whole complexity, than it would be possible by reading the hundreds of papers spread in the literature.

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