Applied problems of nonlinear oscillation and wave theory

Izv.VUZ «AND», vol. 6, № 4, 1998

SCALE PROPERTIES OF RANDOM OPTICAL FIELDS: FUNDAMENTALS AND APPLICATIONS

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Scaling analysis of speckle intensity fluctuations induced by coherent light scattering by dynamic inhomogeneous media is carried out for different types of scattering systems. Relations between box dimensions of the intensity time series and corresponding dimensions describing structure or dynamics of the scattering object have been obtained for single scattering systems such as pre-fractal phase screens and ensembles of Brownian particles as well as for multiple scattering objects. Some applications for morphological analysis of the optically inhomogeneous tissues are discussed.

Introduction

Analysis of statistical and correlation properties of the spatial-temporal fluctuations of scattered optical fields is one of the basic techniques of the study of single and multiple scattering media. These fluctuations are induced by the stochastic phase modulation when coherent light propagates through dynamic scattering medium. One of the most characteristical examples of such dynamic light scattering is the detection of *temporal* intensity fluctuations of the scattered light in the classical experiments with ensembles of Brownian particles [1]. On the contrary, single and multiple scattering of coherent light by «steady-structure» objects lead to the formation of stationary speckle patterns associated with random interference fields; in this case statistical and correlation analysis of *spatial* fluctuations of speckle intensity can be used for characterization of the scattering system or «time-domain» approach also can be used for fixed-point detection conditions in combination with translation movements of the scattering object [2].

Assumptions on the ergodicity and the stationarity of scattering systems as well as on Gaussian statistics of the scattered field with zero mean value are valid for a lot of the scattering dynamic systems consisting of a large number of elementary scatterers (except some specific cases; see, e.g., some comments in [3] on non-ergodic scattering systems). This allows to find the relation between second-order statistical moments of the field and intensity fluctuations of the scattered optical fields through Siegert formula [1].

It should be noted that one of the fundamental properties of the scattered optical fields caused by the stochastisity of the scattering process as well as by the inner properties of the scattering dynamic systems is the scale behavior of the statistical moments of the field and intensity fluctuations. In certain cases such scale behavior can be interpreted as the manifestation of the fractality of random optical fields. The aim of this work is the analysis and classification of the various characteristical examples of pre-fractal behavior of the dynamic optical fields (here and further the term «pre-fractal» means that analyzed systems and processes demonstrate fractal properties in the limited regions of temporal or spatial scales [4]). Some applications of the scaling analysis of the scattered light intensity fluctuations for monitoring and visualizing of the structure of scattering objects will be discussed.

Speckle intensity fluctuations as generalized Brownian process

Spatial-temporal randomness is the principal property of optical fields induced due to dynamic scattering of coherent light by inhomogeneous media. Another principal property of the stochastic interference patterns very often observed in scattering experiments with different types of dynamic media is specific self-affinity [4,5] of intensity time series detected in the fixed point in the scattering experiments. For example, such self-affinity appears when correlation characteristics of the detected signal (which is associated with the analyzed process) are evaluated as the statistical moments of the difference of signal values obtained with given time delay τ; in general, these moments exhibit asymptotic power-law dependencies on τ with an arbitrary exponent.

Taking into account common property of the fractal objects which is the difference between the object's fractal dimension (e.g., box dimension) and its topological dimension (e.g., for continuous but non-differentiated fractal curves their box dimensions are larger than 1), we can interpret such peculiar behavior of the detected intensity time series as the manifestation of «fractality» [4].

It is necessary to note that fractal behavior observed in the limited region of spatial and temporal scales (i.e., pre-fractality) is not an exotic property; on the contrary, a great number of natural and artificial systems and objects show similar properties and, as a rule, corresponding intervals of pre-fractality cover no more than 1.5÷2 decades in the spatial or temporal region (for example, see Sayles and Thomas [6]; see also critical review of the «abundance» of fractals by Avnir et al. [7]).

One of the easiest ways to estimate fractal dimension of the random one-dimensional process (such as, e.g., intensity time series observed in the scattering experiments) for a given range of scales is the evaluation of the exponent of the corresponding structure function introduced as

$$S_I(\tau) = \langle\{I(t+\tau) - I(t)\}^2\rangle \sim \tau^{\nu_I}. \tag{1}$$

In particular, as it follows from analysis carried out by M.Berry ([8], see also [4]) fractal dimension D_I is related with ν_I as

$$D_I = 2 - \nu_I/2. \tag{2}$$

Thus, for «conventional», «physically differentiated» processes characterized by approximately quadratic form of autocorrelation function in the vicinity of zero value of its argument ν=2 and, correspondingly, D=1. On the other hand, so-called Ornstein-Uhlenbeck process [9] is characterized by ν=1; this allows to estimate fractal dimension as 1.5. More commonly, value D=1.5 is typical for classical Brownian fractal curves describing the current displacement of the Brownian random walker with respect to its initial position [4].

Mandelbrot and Van Ness [10] have introduced the concept of generalized, or fractional, Brownian process for identification of pre-fractal processes which are characterized by the structure functions with an arbitrary values of exponent ν taking values from 0 to 2. Below we will take into consideration following dynamic scattering systems inducing speckle intensity fluctuations as generalized Brownian process when coherently illuminated:

- single scattering moving fractal phase screens;
- single scattering ensembles of Brownian particles;
- multiple scattering Brownian ensembles and moving «steady-structure» scatterers.

Moreover, «conventional» intensity fluctuations with ν_I=2 and D_I=1 (e.g., characterized by Gaussian power spectrum) can be considered as a particular case of the generalized Brownian process.

Single scattering systems inducing fractional Brownian intensity fluctuations

a. Moving random screens with fractal structure. Let us consider scattered field formation in the case of coherent beam diffraction on the moving amplitude and phase screens. By introducing such optical model as amplitude or phase screen to describe absorbing or scattering medium and using scalar diffraction approach we do not take into account an influence of optical thickness of medium layer on the scattered field formation and shall characterize this layer by two-dimensional distribution of amplitude or phase transmittance (or reflectance) coefficient $t(x,y)$. Moreover, we should restrict our analysis only by the case of large-scale amplitude or phase inhomogeneities with characteristical sizes larger than wavelength used [11].

Despite these strong limitations such approach is adequately proper for the analysis of the diffraction fields induced by the wide variety of the coherently illuminated optically inhomogeneous objects (e.g., rough surfaces, thin layers of biotissues, etc.).

For the transverse movement of the coherently illuminated screen we can express current intensity in the on-axis detection point as [12,13]:

$$I(\bar{\xi}) = |\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} A(x,y)U(x-\xi_x,y-\xi_y)dxdy|^2, \qquad (3)$$

where $A(x,y)$ is the generalized aperture function of the optical system used, which is determined by the distribution of the complex amplitude in the illuminating beam and detection conditions. For example, in the case of screen position in the waist plane of the Gaussian illuminating beam and detection point position in the paraxial region of the Fresnel diffraction zone generalized aperture function is:

$$A(x,y) = A_0\exp\{-(x^2+y^2)/w_0^2\}\exp\{j\pi(x^2+y^2)/(\lambda Z)\}, \qquad (4)$$

where w_0 is the waist radius of the illuminating beam, A_0 is on-axis beam amplitude, λ is wavelength of the probe beam and Z is the distance between screen and detection planes. $U(x,y)$ describes the boundary field distribution which is formed immediately behind the scattering object illuminated by the plane wave with uniformly distributed amplitude equal to 1. For pure amplitude screens $U(x,y)=t(x,y)$ and, respectively, for pure phase screens $U(x,y)=\exp[jt(x,y)]$ (in this case $t(x,y)$ describes phase perturbation of the probe coherent beam). Term «transverse movement» means that screen displaces in the direction perpendicular to optical axis of the illuminating beam; displacement is determined by the module of vector ξ. The integral transform in the right part of Eq. (3) can be considered as convolution of the generalized aperture function $A(x,y)$ and boundary field distribution $U(x,y)$. Thus, Fourier spectrum of the current intensity fluctuations in the detection point caused by screen displacement can be expressed as:

$$F_I(\bar{\omega}_\xi) = \{F_A(\bar{\omega})F_U(\bar{\omega})\}\otimes\{F_A^*(\bar{\omega})F_U^*(\bar{\omega})\}, \qquad (5)$$

where symbol * denotes complex conjugation, $F_A(\bar{\omega})$ and $F_U(\bar{\omega})$ are Fourier spectra of the generalized aperture function and boundary field amplitude.

For random screens with spatial distributions of the local values of transmittance coefficient $t(x,y)$ demonstrating fractal properties translation movements with constant velocity will induce time-dependent intensity fluctuations with properties of the generalized Brownian process. Relation between such parameter of the fractal distribution $t(x,y)$ as fractal dimension and corresponding fractal dimension of the observed speckle intensity fluctuations can be obtained using the analysis of Eq.(5). In particular, theoretical analysis of the relationships between fractal dimensions of spatial fluctuations of the boundary field amplitude with zero mean value and phase and temporal fluctuations of the speckle intensity in the paraxial region of the far diffraction zone with experimental verification of the obtained results was carried out in [12, 13] for the cases of the broad collimated and sharply focused beam illumination of the 2-D-isotropic pre-fractal phase screens characterized by large-scale phase inhomogeneities. Thus, there is no necessity to discuss all details of this study, and for this reason only the brief review of the principal results will be given here. For broad collimated illuminating beam and far zone detection (in this case far diffraction zone is considered with respect to maximal characteristical size of the screen structure, and we analyze model of the unbounded screen illuminated by the plane wave with uniform amplitude distribution) equality of the fractal dimensions of the detected intensity fluctuations and boundary field amplitude will take place. It should be noted that such equality was obtained for the values of fractal dimension of the boundary field amplitude estimated for arbitrary selected one-dimensional cross-section of the two-dimensional isotropic distribution of the boundary field amplitude. Following the results of analysis presented by B.Mandelbrot (see, e.g., [5]), we can use relation between 1-D and 2-D fractal dimensions of the isotropic spatial distributions:

$$D^{(2)} = D^{(1)} + 1. \qquad (6)$$

For sharply focused beam, when $A(x,y)\sim\delta(x,y)$ and, correspondingly, $F_A(\bar{\omega})\sim$const, we will observe increased values of the fractal dimension of the speckle intensity fluctuations in comparison with the fractal dimension of isotropic boundary field (i.e., «chaotization» of the speckle intensity takes place). For random phase screens inducing statistically homogeneous and isotropic fractal distributions of the boundary fields with zero mean field fractal dimensions of intensity and amplitude are related with each other as:

$$D_I = 2D_u - 1, \qquad (7)$$

where D_u is fractal dimension of the boundary field fluctuations determined by using one-dimensional arbitrary selected cross-section. This expression follows from the relationships between exponents of power spectra and structure functions of two-dimensional isotropic random distributions satisfying Eq.(5) [12,13]. So, Brownian fractal distributions with 1-D fractal dimension equal to 1.5 induce «extreme» fractal intensity fluctuations with D_I=2. Similar analysis carried out for the case of one-dimensional («corrugated») amplitude fractal screens illuminated by sharply focused coherent beam gives the less strong criterion of the «full chaotization» (D_I is close to 2) of the intensity fluctuations of the scattered field: extreme value of D_u will be equal to 1.75.

Relation between fractal properties of spatial disributions of the boundary field phase and amplitude which is necessary for inverse problem of fractal structure characterization is determined by the relation between their structure functions. In particular, for phase screens with Gaussian statistics of boundary field phase fluctuations transverse coherence function of the boundary field will be related with structure function of the boundary field phase as (if mean boundary field is equal to zero) [11]:

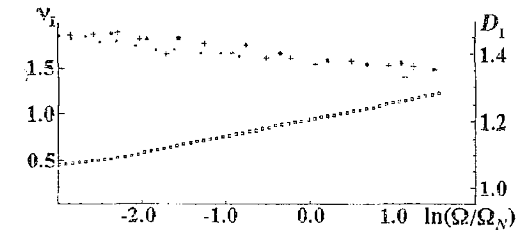

Fig. 1. Dependencies of structure function exponent ν_I (■,*,+) and fractal (box) dimension D (□) of near zone intensity fluctuations on halfwidth of Fourier spectrum module of generalized aperture function. Experiment with fine-structured moving ground glass. Markers (■,*,+) correspond to different values of illuminating beam waist radius (taken from [14])

$$g_u(\Delta\bar{r}) \approx \exp(-D_l(\Delta\bar{r})/2). \qquad (8)$$

For phase screens with large-scale inhomogeneities we can use simple asymptotic form of in the region of small spatial scales such as: $g_u(\Delta\bar{r}) \approx 1 - D_l(\Delta\bar{r})/2$, and, correspondingly, we will have the asymptotic equality of D_u and D_l. With an increase of induced phase modulation depth additional «chaotization» of the boundary field amplitude fluctuations will take place.

In the intermediate case of limited width of $A(x,y)$ spectrum relationship between and has the more complicated character and value of D_I will be less than upper value of fractal dimension calculated by using Eq. (7). Thus, with the broadening of spatial spectrum of the generalized aperture function D_I will increase up to this extreme value. Similar behavior is illustrated by the dependence of D_I on the halfwidth of $A(x,y)$ spectrum (see Fig.1) obtained in the experiments with fine-structured ground glasses [14]. Used experimental conditions (detection of the speckle intensity fluctuations in the Fresnel diffraction zone and Gaussian illuminating beam) allowed to vary the halfwidth of the aperture function spectrum in the wide limits.

Presence of non-zero mean value of boundary field will lead to the distortion of the simple relation between scaling parameters of the boundary field amplitude and far-zone intensity fluctuations given by Eq. (7) in the case of zero mean field. In this case, as it follows from Eq. (5), decay of power spectrum of the speckle intensity fluctuations will be determined by the contribution of «linear» and «quadratic» term; thus, resulting effective value of D_I will be between D_u and value determined by Eq. (7). Such boundary fields with non-zero mean value appear in the case of «pure» amplitude screens and «weak» phase screens (with boundary field phase variance much less than 1).

b. Single scattering Brownian ensembles. Coherent light scattering is traditionally used for analysis of the stochastical systems such as Brownian ensembles consisting of non-interacting particles [1]. In the most simple case of single scattering diluted liquid suspensions of monodisperse spherical particles autocorrelation function of the scattered field has the well-known classical exponential form [1]:

$$g_1(\tau) = \exp(-\Delta_T q_\theta^2 \tau)\exp(-j\omega\tau),$$

where Δ_T is the translation diffusion coefficient and q_0 is scattering vector module equal to $(4\pi n_0/\lambda)\sin(\theta/2)$, where n_0 is refractive index and θ is scattering angle. For ideal detection conditions normalized intensity autocorrelation function looks as (by using the Siegert relation [1], $g_2(\tau)=1+\beta|g_1(\tau)|^2$, for ideal detection conditions $\beta=1$):

$$g_2(\tau) - 1 = \exp(-2\Delta_T q_\theta^2 \tau). \qquad (9)$$

Thus, it is easy to see that in the region of small temporal scales intensity fluctuations of the scattered light can be considered as the «classical» Brownian process with $\nu_I=1$, $D_I=1.5$ and topothesy equal to $4\Delta_T q_\theta^2$ (topothesy is parameter of the fractional random curve determining the two points separation for which the average slope of chord between points will be equal to 1 [15]).

For Brownian systems consisting of non-spherical particles, rotation diffusion will give contribution in the decay of correlation of intensity fluctuations; for example, even for simple scattering models such as elliptical particles and rod-like particles field and intensity autocorrelation functions have the more complicated polyexponential form than given above. Nevertheless, for small time scales we can approximate decay of $g_1(\tau)$ and $g_2(\tau)$ by the linear function and also consider intensity fluctuations as classical Brownian process with topothesy determined by the combination of translational and rotational terms with corresponding weighting coefficients. It is necessary to note that for small scattering angles, when $q_\theta L<<1$ (L is characteristical size of non-spherical particle), contribution of rotational diffusion in the formation of speckle intensity fluctuations is negligible and we can take into account only the translational component [1].

Thus, analyzing scale behavior of speckle intensity fluctuations and estimating corresponding values of v and D we can identify single scattering monodisperse Brownian systems. Presence of the regular component of particles movement such as «drift» with constant velocity will add term $\exp(-2v^2 q_\theta^2 \tau^2)$ in the right part of formula (9).

Multiple scattering systems

In the case of multiple scattering dynamic systems observed random interference fields (speckle patterns) demonstrate pre-fractal properties even for regularly moving local scatterers. By using the modified random walk approach for analysis of the time dependent fluctuations of the scattered field complex amplitude in the fixed detection point the following expression for $g_1(\tau)$ can be obtained (see, e.g., [16]):

$$g_1(\tau) \sim \exp(-j\omega\tau)\, \Sigma_n P(n) \exp[-n\langle \bar{q}^2 \rangle B(\tau)/6]. \qquad (10)$$

$B(\tau)$ is determined by the variance of the displacements of local scatterers in the dependence on time delay τ. This expression is obtained as a result of the scattered field consideration as the sum of partial contributions induced by the «chains» of scattering events; each contribution is characterized by the number n of these events; $P(n)$ is weighting function determined by statistics of scattering events; $\bar{q}$ is scattering vector for given scattering event. Thus, we can introduce value of optical path s for scattered field contribution with given n as $s \cong ln$, where l is so-called mean free-path length. In this case we can express $g_1(\tau)$ as:

$$g_1(\tau) \sim \exp(-j\omega\tau) \langle \exp\{-\langle \bar{q}^2 \rangle B(\tau) s/6l\} \rangle \sim \exp(-j\omega\tau) \int_0^\infty \rho(s) \exp\{-\langle \bar{q}^2 \rangle B(\tau) s/6l\} ds. \qquad (11)$$

For optically dense infinite scattering media with embedded coherent point-like source and point-like detector, when diffusion mode [17] of light propagation through medium takes place, $\rho(s)$ is [16]:

$$\rho(s) = [3/(4\pi s l^*)]^{3/2} \exp[-3|\bar{r}-\bar{r}'|^2/(4 s l^*)],$$

where l^* is so-called mean transport length and $|\bar{r}-\bar{r}'|$ is separation between source and detector. In this case field autocorrelation function in the dependence on $B(\tau)$ can be expressed as:

$$g_1(s) \sim \exp(-j\omega\tau) \exp\{-[B(\tau)\langle \bar{q}^2 \rangle / 2 l l^*]^{1/2} |\bar{r}-\bar{r}'|\}, \qquad (12)$$

Thus, for multiple scattering systems consisting of non-interacting Brownian particles $B(\tau)=6\Delta_T\tau$ and, respectively, $g_1(s) \cong \exp(-j\omega\tau)\exp[-(6\tau/\tau_0)^{1/2}|\bar{r}-\bar{r}'|/l^*]$, where $\tau_0^{-1}=4\pi^2 n_0^2 \Delta_T/\lambda^2$. As it was mentioned in [16], similar scale properties of the detected intensity fluctuations are observed for light transmitted through dynamic scattering media with slab geometry, if slab thickness W is much larger than mean transport length l^*.

Using Siegert relation, we can see that intensity fluctuations of the coherent light that undergoes multiple scattering in the ensembles of Brownian particles are characterized the same scale properties as generalized pre-fractal Brownian process with $\nu=0.5$ and $D=1.75$: $g_2(\tau)\approx 2\text{-const }\tau^{1/2}$. In the case of regular translation movement of the «steady-structure» multiplescattering media $B(\tau)$ can be expressed as $B(\tau)=\upsilon^2\tau^2$ (where υ is translation velocity) and $g_2(\tau)\approx 2\text{-const }\tau$. Thus, speckle intensity fluctuations, detected in the fixed point during the translation of the «steady-structure» multiple scattering object with respect to probe coherent beam can be considered as the «classical» Brownian process with $\nu=1$ and $D=1.5$. Thus, specific property of the multiple scattering is an increase of the fractal dimension of the detected optical signal in comparison with corresponding dimension describing dynamic properties of the given scattering system; we can interpret such property as manifestation of «chaotization» effect in multiple scattering. Even in the case of regular movements of local scatterers (such type of particle dynamics can be interpreted as «marginal» fractal process [15] with $\nu=2$ and fractal dimension equal to 1) intensity fluctuations demonstrate fractal behavior characterized by value of D larger than 1. In the extreme case of diffusion mode of coherent light propagation through multiple scattering media effect of «chaotization» can be described by the following simple expression:

$$D_{\mathrm{I}} = 1 + D_{\mathrm{d}}/2, \tag{13}$$

where D_{d} is determined by the dynamic properties of the scattering system.

Asymptotic behavior of the autocorrelation and structure functions of the detected speckle intensity fluctuations strongly depends on the form of $\rho(s)$, or, in the same way, on the optical paths statistics. Suppression of the pure diffusion mode of light transport through scattering media and, correspondingly, increased contribution of the unscattered component and components of scattered field induced by small numbers of scattering events lead to increase of the structure function exponent ν_{I} and, correspondingly, diminishing of D_{I}. Similar «cut-off» of the field contributions characterized by the high level of randonmess due to large values of s can be made by the dilution of scattering component or by choose the detection conditions corresponding to probability density $\rho(s)$ with «suppressed» tail. Thus, strong dependence of scaling parameters on form of optical paths distribution will be observed in the region of cross-over between multiple scattering and single scattering modes. Fig.2 illustrates the evolution of logarithmically scaled structure function of speckle intensity fluctuations in the cross-over region for multiple scattering water suspensions of polystyrene spheres with the diminishing of scattering particles concentration. «Chaotization» of the speckle intensity fluctuations in the case of the regularly moving multiple scattering media with an increase of contribution of long-path components of the scattered field due to variation of the detection conditions has been observed in the experiments with slab-geometry phantom samples [18].

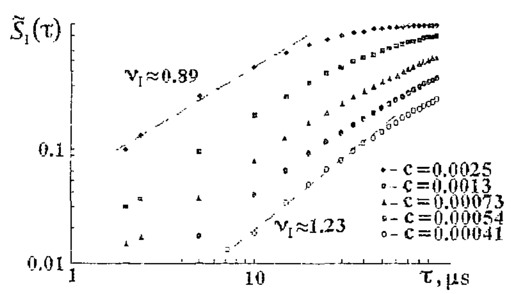

Fig. 2. Evolution of the structure function of the transmitted light intensity fluctuations with the transition from multiple scattering to single scattering mode. Object under study - water suspensions of 0.46-μm polystyrene spheres. Illumination source - Ar laser (λ=514 nm); detector unit - HC-120 (Hamamatsu) photomultiplier tube with single-mode fiber. Signal processing unit - BIC-9000 digital correlator

Applications

Possible applications of the scaling analysis of the speckle intensity fluctuations are related to non-contact «speckle» profilometry [12,13] and morphological investigations of the relatively thin tissue samples [2,19-21] as well as the studies of the regular and random motions of the various tissue fluids. Local estimations of ν_I (and, correspondingly, D_I) during tissue scanning by the probe coherent beam demonstrate high sensitivity to the variations of optical parameters of tissue in the intermediate region between single scattering and multiple scattering modes. One of the most characteristical examples of such sensitivity of scale parameters of the speckle intensity fluctuations to the changes of the tissue scattering state are the experiments with optically cleared human sclera [2,20]. Native sclera is typically multiple scattering object due to its specific optical properties (large values of scattering coefficient - typical values are of the order of 25 cm^{-1} and relatively low values of absorption coefficient) caused by structural peculiarities [20]. Diffusion of some agents (such as derivatives of triiodobenzene acid or another liquids like glucose with refractive indices close to 1.4) leads to the suppression of the multiple scattering processes and transition to the single scattering mode of light propagation through sclera. Correlation experiments with optically cleared sclera made by using focused He-Ne laser beam scanning showed that such clearing process is accompanied by the sharp increasing of ν_I from the values close to 1 (as it is mentioned above this value is typical for speckle intensity fluctuations induced by regularly moving multiple scattering media) up to the values close to 2 (Fig.3, *a*) The last value is typical

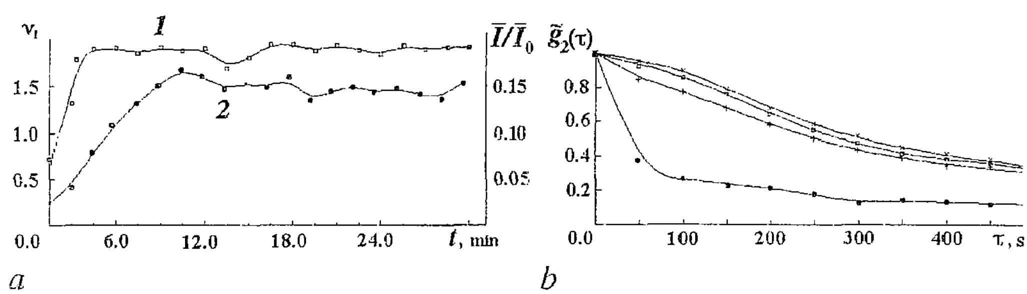

Fig. 3. *a* - Dependencies of the structure function exponent ν_I (*1*) and normalized collimated transmittance $\bar{I}/\bar{I}_0$ (*2*) on time elapsed after immersion agent application for optically cleared sclera (taken from [2]); *b* - Evolution of the form of normalized autocorrelation function of intensity fluctuations with the transition from multiple scattering to single scattering mode for optically cleared human sclera (taken from [2]). Scanning by focused He-Ne laser beam; scanning velocity is equal to 5 mm/s. Time elapsed after immersion agent application: ● - 100 s; + - 200 s; ■ - 400 s; × - 500 s

for the case of single scattering of Gaussian beam by the fine-structured media moving with constant velocity across the illuminated area [11]. Fig.3, *b* shows the characteristical changes of the forms of modified intensity autocorrelation function $\tilde{g}_2(\tau)=g_2(\tau)-1$ caused by optical clearing of the sclera sample. For early stages of process form of $\tilde{g}_2(\tau)$ is rather «exponential» but for the later stages it is rather «Gaussian». Such property of ν_I and D_I as high sensitivity to tissue scattering characteristics in the intermediate region between different scattering modes makes the scaling analysis of the scanning-induced intensity fluctuations an attractive tool for monitoring and imaging of tissue structures in the morphological analysis. Good example of similar application is *in-vitro* imaging of the structure of thin tissue samples by using the local estimations of ν_I exponent [2,21]; reconstructed in such a way two-dimensional images («maps») of the spatial distributions of local estimations of ν_I clearly show spatial macro-inhomogenities of the tissue structure (e.g., stimulated by disease progress). Result of applications of such «mapping»

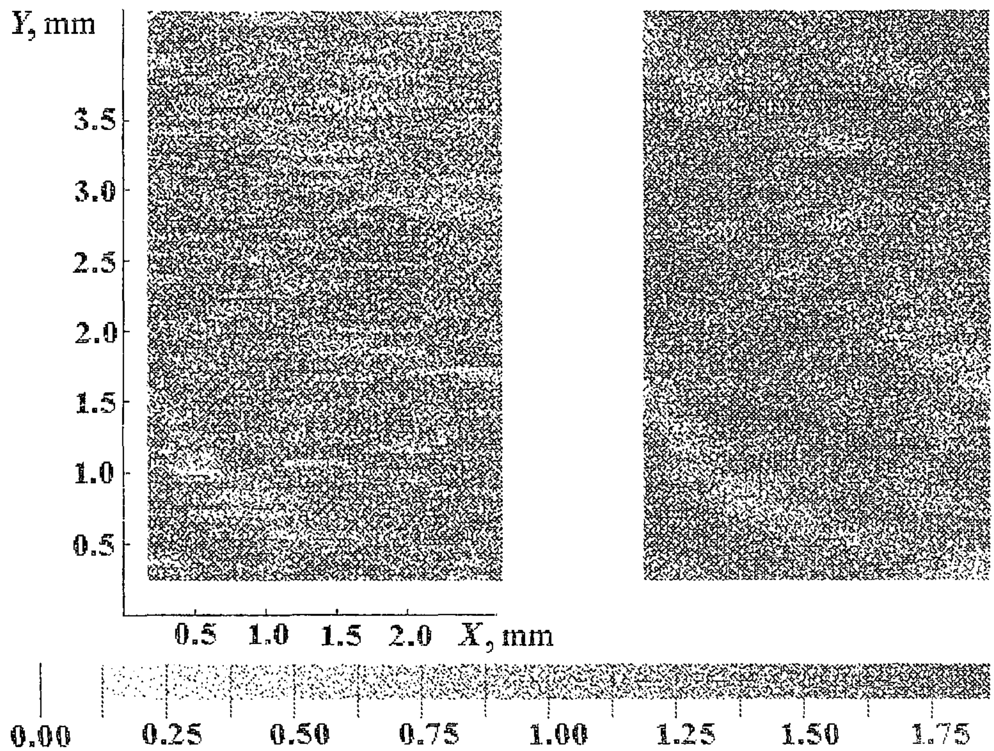

Fig. 4. 2*D*-images («maps») of the diseased (psoriatic) human epidermis made by using local estimations of the structure function exponent ν_I (early stage of disease). Scanning by He-Ne laser beam; left image - focused scanning beam; right image - broad collimated beam. Taken from [2]

technique for *in-vitro* structure analysis of the human epidermis is illustrated by Fig.4 (see, e.g., [2] for detailed qualitative interpretation of changes of epidermis scattering structure caused by psoriasis progress).

Conclusion

As we can see, fractional character [10] of the noise-like speckle intensity fluctuations allowing to interpret them as pre-fractal processes can be caused by inner structure or dynamics of the scattering system as well as by the stochastisity of the multiple scattering. For non-absorbing optically inhomogeneous dynamic media relation between structure function of the field fluctuations and structure function of the phase perturbations of the probe optical field has the exponential form. This gives asymptotical linear dependence of the field scaling parameters (e.g., box dimension) on corresponding phase scaling parameters only for temporal or spatial scales characterized by local phase variance much less than 1. As a rule, interval of self-affinity associated with «pure» fractal behavior span around 1.5÷2.0 orders of magnitude. Nevertheless, such limitation is the common property of the wide variety of empirical fractal objects caused by their random nature [7].

The research described in this publication was made possible in part by Award N RB1-230 of the US Civilian Research & Development Foundation for the Independent States of the Former Soviet Union (CRDF) and by Award N 96-15-96389 («Leading scientific schools of Russia») of the RFBR.

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Received 18.05.98

УДК 535.24; 535.6

МАСШТАБНЫЕ СВОЙСТВА СЛУЧАЙНЫХ ОПТИЧЕСКИХ ПОЛЕЙ: ФУНДАМЕНТАЛЬНЫЕ АСПЕКТЫ И ПРИЛОЖЕНИЯ

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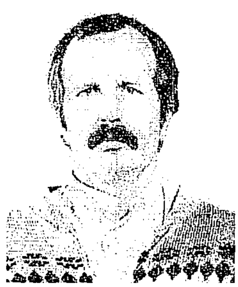
Рассмотрены масштабные свойства флуктуаций интенсивности спеклов, образующихся при рассеянии когерентного излучения динамическими пространственно-неоднородными средами в случае различных типов рассеивающих систем. Получены соотношения между емкостной размерностью временных реализаций наблюдаемых флуктуаций интенсивности спеклов и соответствующей размерностью, характеризующей структуру или динамику рассеивающего объекта как в режиме однократного рассеяния (префрактальные фазовые экраны и ансамбли броуновских частиц) так и для многократно рассеивающих систем. Обсуждаются некоторые приложения анализа масштабных свойств флуктуаций интенсивности для морфологических исследований биотканей.



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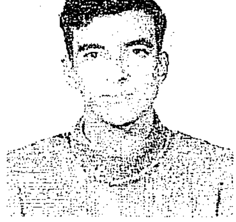

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