IMAGING OF ILLUMINATED OBJECTS IN A RANDOM DISCRETE MEDIUM

V.A. Banakh, E.V. Zakharova, and B.N. Chen

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
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We discuss here imaging of an object illuminated through a discrete large-scale random medium. The effect of correlation between the illuminating and return waves passed through the same randomly distributed scatterers on the object image is analyzed. It is shown that correlation of the counter waves can lead to a significant enhancement of the coherent component of an optical image and can enable us to observe distant objects in turbid media which are indistinguishable in a discrete medium under lateral illumination when no such correlation occurs.

INTRODUCTION

Double passage imaging through a random screen as well as through continuous randomly inhomogeneous media including such geometry when the object is illuminated and viewed from one and the same point has been studied in a number of papers.[1–3] The backscatter enhancement effect caused by the correlation of counter waves in the discrete random media is also of great interest both as a physical phenomenon and from the view point of possible applications. This effect is observed in dense scattering media with scatterers of the size comparable to the wavelength of illuminating light or less.[4] The backscatter enhancement effect also takes place in rarefied large-scale discrete random media with the scatterer size considerably exceeding the wavelength of radiation.[4–6] In Refs. 4–6 the backscatter effects are considered for the case of depth regime when the reflected wave is formed as a result of multiple scattering on the discrete inhomogeneities of the medium.

In this paper we consider analogous problem for the case when the reflected wave in the large-scale discrete random medium is a result of reflection of radiation from a reflecting surface. The influence of correlation between the illuminating and reflected waves on the object image in such a medium is analyzed.

PROPAGATION OF OPTICAL WAVES ALONG THE PATHS WITH REFLECTION IN RANDOM DISCRETE MEDIUM

Complex amplitude of an optical wave propagating in a discrete medium with randomly distributed particles whose size a_0 considerably exceeds the wavelength λ yields the following parabolic equation[7]

$$\left[2ik\frac{\partial}{\partial x'} + \Delta\rho' - \sum_{j=1}^{N} v_j\,(x', \rho')\right] u\,(x', \rho') = 0\ , \qquad (1)$$

where $k = 2\pi/\lambda$ is the wave number, $\Delta\rho = \left\{\frac{\partial^2}{\partial y^2}, \frac{\partial^2}{\partial z^2}\right\}$ is the transverse Laplacian, $v_j\,(x, \rho)$ is the scattering potential of the jth particle, N is the number of particles. Let us assume that Eq. (1) describes the wave propagation along the Ox' axis from left to right and on the left boundary $x' = x_0$ the condition $u\,(x', \rho')\big|_{x' = x_0} = u_0(\mathbf{t})$ is true. The solution of Eq. (1) for an arbitrary plane $x' = x \geq x_0$ is

$$u\,(x, \rho') = \int \mathrm{d}^2t\ u_0(\mathbf{t}) G\,(x, x_0;\, \rho', \mathbf{t})\ ,$$

where $G\,(x, x_0;\, \rho', \mathbf{t})$ is the Green function of Eq. (1) satisfying the equation

$$\left[2ik\frac{\partial}{\partial x'} + \Delta\rho' - \sum_{j=1}^{N} v_j\,(x', \rho')\right] G\,(x', x_0; \rho', \mathbf{t}) = 0$$

under boundary condition

$$G\,(x_0, x_0;\, \rho', \mathbf{t}) = \delta(\rho' - \mathbf{t}).$$

Assume that the wave is reflected in the plane $x' = x$ and the field on the reflecting surface is

$$u_0^R(\mathbf{r}) = \int \mathrm{d}^2\rho'\ u\,(x, \rho') O(\rho', \mathbf{r})$$

where $O(\rho', \mathbf{r})$ is the function representing the local reflection coefficient. The complex amplitude of the wave propagating backward $u^R(x', \rho)$ satisfies the equation

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$$\left[-2ik\frac{\partial}{\partial x'} + \Delta\rho - \sum_{j=1}^{N} v_j\,(x', \rho)\right] u^R(x', \rho) = 0 \,. \qquad (2)$$

Since Eqs. (1) and (2) are conjugate, the Green function $G^R(x', x_0; \rho, \mathbf{t})$ of Eq. (2) is related to Green function G by the relation

$$G^R(x', x; \rho, \mathbf{t}) = G\,(x, x'; \mathbf{t}, \rho) \,. \qquad (3)$$

This enables us to write the reflected wave field in the plane $x' = x_0$ in the form

$$u^R(x_0, \rho) = \int d^2t\; u_0(\mathbf{t}) \times$$

$$\times \int d^2\rho' \int d^2r\; O(\rho',\mathbf{r})G\,(x,x_0;\rho',\mathbf{t})G\,(x,x_0;\mathbf{r},\rho) \,. \qquad (4)$$

In what follows, for the analysis of coherent optical images we will need the second statistical moment of the reflected wave field in the plane $x' = x_0$

$$\Gamma^R(x_0;\rho_1,\rho_2) = \langle u^R(x_0, \rho_1)\, u^{R*}(x_0, \rho_2) \rangle \,,$$

where <...> denotes averaging over an ensemble. When we calculate the statistically average fluctuations of the medium parameters, we shall assume that the parameters of the initial field, and the local reflection coefficient, which can also be random, are statistically independent. Thus, according to Eq. (4) the mutual coherence function Γ^R is given by

$$\Gamma^R(x_0;\rho_1,\rho_2) = \int d^2t_{1,2} \langle u_0(\mathbf{t}_1)u_0^*(\mathbf{t}_2) \rangle \times$$

$$\times \int d^2\rho'_{1,2} \int d^2r_{1,2} \langle O\,(\rho'_1,\mathbf{r}_1)O^*(\rho'_2,\mathbf{r}_2) \rangle \times$$

$$\times \langle G\,(x, x_0; \rho'_1, \mathbf{t}_1)G^*(x, x_0; \rho'_2, \mathbf{t}_2) \times$$

$$\times G\,(x, x_0; \mathbf{r}_1, \rho_1)G^*(x, x_0; \mathbf{r}_2, \rho_2) \rangle \,. \qquad (5)$$

Consequently, to calculate the second moment of the reflected wave field, the fourth moment of the Green function of Eq. (1) describing the wave propagation along the direct path ought to be known.

We shall assume that positions of the particle centers r_j in the medium are distributed uniformly and the probability for N particles being in the volume V is determined by the Poisson law. It can be shown[8] that the propagating wave field in this case can be considered as Gaussian one because of the central limit theorem. A closeness of the distribution law of field complex amplitude to the normal one for the optical thickness $\tau > 1$ is also confirmed by the experimental data for laser beam propagation through precipitation.[9] That allows us to use the following approximation in Eq. (5)

$$\langle G(x, x_0; \rho'_1, \mathbf{t}_1)G^*(x, x_0; \rho'_2, \mathbf{t}_2)G\,(x, x_0; \mathbf{r}_1, \rho_1)G^*(x, x_0; \mathbf{r}_2, \rho_2) \rangle \approx$$
$$\approx \langle G(x, x_0; \rho'_1, \mathbf{t}_1)G^*(x, x_0; \rho'_2, \mathbf{t}_2)\rangle \langle G(x, x_0; \mathbf{r}_1, \rho_1)G^*(x, x_0; \mathbf{r}_2, \rho_2)\rangle +$$
$$+ \langle G(x, x_0; \rho'_1, \mathbf{t}_1)G^*(x, x_0; \mathbf{r}_2, \rho_2)\rangle \langle G(x, x_0; \mathbf{r}_1, \rho_1)G^*(x, x_0; \rho'_2, \mathbf{t}_2)\rangle. \qquad (6)$$

The condition $a_0 \gg \lambda$ and the use of the parabolic equation (1) means that the field scattered by particles along directions in the back half-plane is zero. Therefore, the order of wave scattering (forward) by N particles does not exceed N and the particles can be considered as amplitude–phase screens[7] owing to the inequality $a_0/L \ll 1$, where $L = x - x_0$. The complex of these conditions enables us to propose the δ–correlation of fluctuations of the discrete random medium along the direction of wave propagation and the use of diffuse approximation[10] to derive equations for the statistical moments of the field complex amplitude in such a medium[7].

According to Ref. 7, for the second moment of the Green function in Eq. (6) we have

$$\left\{2ik\frac{\partial}{\partial x'} + (\Delta\rho_1 - \Delta\rho_2) + \alpha_c[2s - F\,(\rho_1 - \rho_2)]\right\} \times$$

$$\times \langle G(x', x_0; \rho_1, \mathbf{t}_1)G^*(x', x_0; \rho_2, \mathbf{t}_2) \rangle = 0 \,, \qquad (7)$$

where $\alpha_c = 2ikc$, c is the particle number density, $s = \int d^2\rho \langle S\,(\rho) \rangle$ is the mean square of a particle projection (shadow) on the plane x = const, $S\,(\rho)$ is the shadow characteristic function (equal to unity within the shadow and to zero out of it), $F\,(\rho) = \frac{1}{s}\int d^2\rho' \langle S\,(\rho')S\,(\rho - \rho') \rangle$ is the shadow autocorrelation function. We assume that in the functions s and F averaging is carried out over the particle dimensions and orientation.

The solution of Eq. (7) has the form[7]

$$\langle G(x, x_0; \rho_1, \mathbf{t}_1)G^*(x, x_0; \rho_2, \mathbf{t}_2)\rangle =$$

$$= \left(\frac{k}{2\pi L}\right)^2 \exp\left\{\frac{ik}{2L}\,[(\rho_1 - \mathbf{t}_1)^2 - (\rho_2 - \mathbf{t}_2)^2]\right\} \times$$

$$\times \exp\left\{-\tau + \frac{\tau}{2}\int_0^1 d\xi F[\xi(\rho_1 - \rho_2) + (1 - \xi)\,(\mathbf{t}_1 - \mathbf{t}_2)]\right\} \,, \qquad (8)$$

where $\tau = 2csL$ is the optical thickness.

The derived expression (8) is of the same form as that for a turbulent medium[10] except for the additional term in the second exponent which describes the wave intensity attenuation due to scattering by particles and for the form of the medium function F.

OPTICAL TRANSFER FUNCTION OF A DISCRETE RANDOM MEDIUM FOR THE PATH WITH REFLECTION

The mean intensity distribution over the object image $< I_t (l,\rho'') >$ and the function Γ^R are related by the following equation[11]

$$< I_t (l,\rho'') > = \int d^2\rho_{1,2} T(\rho_1) T(\rho_2) \times$$

$$\times \Gamma^R(x_0;\rho_1,\rho_2) \exp\left\{ \frac{ik}{2l}\left(1 - \frac{l}{F_t}\right) \times\right.$$

$$\left. \times (\rho_1^2 - \rho_2^2) - \frac{ik}{l}(\rho_1 - \rho_2)\rho'' \right\} \qquad (9)$$

where $T(\rho)$ is the amplitude coefficient of the receiving lens with the focal length F_t , l is the distance from the lens entrance pupil to the image plane.

In the particular case of a diffusely scattering object

$$< O(\rho'_1,\mathbf{r}_1) O^*(\rho'_2,\mathbf{r}_2) > = \frac{4\pi}{k^2} < A(\mathbf{r}_1) A^*(\mathbf{r}_2) > \times$$

$$\times \delta(\mathbf{r}_1 - \mathbf{r}_2)\delta(\rho'_1 - \mathbf{r}_1)\delta(\rho'_2 - \mathbf{r}_2) \qquad (10)$$

where $A(\mathbf{r})$ is the amplitude factor, $\delta(\rho)$ is the Dirac delta function, and incoherent light

$$< u_0(\mathbf{t}_1) u_0^*(\mathbf{t}_2) > = \frac{4\pi}{k^2} I_0(\mathbf{t}_1)\, \delta(\mathbf{t}_1 - \mathbf{t}_2)$$

where $I_0(\mathbf{t})$ is the intensity at the point $\mathbf{t}$, the expression (9) may be interpreted using the concept of the optical transfer function (OTF).

If we introduce the spatial spectrum of the object

$$\tilde{I}_{ob}(\omega) = \int d^2 r < A(\mathbf{r}) A^*(\mathbf{r}) > \exp\left(-\frac{il}{L}\omega\mathbf{r}\right)$$

and functions

$$H_0(\omega) = \int d^2\rho\, T(\rho) T\left(\rho - \frac{l}{k}\omega\right),$$

$$H(x,0;0,\omega) = \exp\left[-\tau + \frac{\tau}{2}\int_0^1 d\xi\, F\left(\xi \frac{l}{k}\omega\right)\right],$$

then from Eq. (9) for the spatial spectrum of the object image $< \tilde{I}_t (l,\omega) >$ taking into account only the first term in Eq. (6) we find the following expression

$$< \tilde{I}_t (l,\omega) >_1 = \left(\frac{k}{2\pi L}\right)^4 I_\Sigma\, \tilde{I}_{ob}(\omega) H_0(\omega) H(x,0;0,\omega) \qquad (11)$$

where $I_\Sigma = \int d^2 t\, I_0(\mathbf{t})$.

The expression (11) is nothing but the spatial spectrum of the diffuse object image in a scattering medium, and the functions $H_0(\omega)$ and $H(x, 0; 0, \omega)$ have the meaning of optical transfer functions of the receiving optical system and the medium, respectively.

By making similar calculations in Eq. (9) with the use of the second term in Eq. (6) we obtain

$$< \tilde{I}_t (l,\omega) >_2 = \left(\frac{k}{2\pi L}\right)^4 \tilde{I}_{ob}(\omega)\, \Phi(\omega) , \qquad (12)$$

where

$$\Phi(\omega) = \int d^2\rho\, T(\rho) T\left(\rho - \frac{l}{k}\omega\right) H_{co}(\rho,\omega) ,$$

$$H_{co}(\rho,\omega) = \int d^2 t\, I_0(\mathbf{t}) \times$$

$$\times H\left(x,0;\,0,\mathbf{t} - \rho + \frac{l}{k}\omega\ \ H(x,0\right) 0, \rho - \mathbf{t}) \quad .$$

By analogy with the Eq. (11), the function $\Phi(\omega)$ can be considered as a combined optical transfer function of the optical system and the scattering medium. It is impossible to separate out the contributions coming from the medium and the optical system into the distortions of the object image in this case.

By adding the expressions (11) and (12) we obtain that the spatial spectrum of the object image is presented as the product of the object spatial spectrum by the optical transfer function

$$H_\Sigma(\omega) = H_0(\omega) H(x,0;0,\omega) + I_\Sigma^{-1}\, \Phi(\omega) \qquad (13)$$

involving two terms. The first term coincides with the OTF for the diffuse object and describes the optical image distortions caused by diffraction on the elements of optical system and wave scattering by the medium inhomogeneities along the path from an object to receiver. The second term owes its origin to the double passage of optical wave through the same random scatterers of the medium when propagating in the forward and backward directions. As a result, the correlation between the illuminating and reflected waves occurs. Allowance for the first term only in Eq. (13) means that the illumination source and receiving telescope are considerably spaced.

COHERENT IMAGE OF A POINT OBJECT IN A SCATTERING MEDIUM

Let us assume that a point (distant) object with the reflection coefficient

$$O\,(\rho',\mathbf{r}) = \frac{4\pi}{k^2}\,\delta(\rho')\delta(\rho' - \mathbf{r})\ , \tag{14}$$

is illuminated with a coherent optical radiation

$$u_0(\mathbf{t}) = u_0 \exp\left(-\frac{t^2}{2a^2} - \frac{ikt^2}{2F}\right), \tag{15}$$

where a and F are the radius and focal length of a coherent beam. As discrete scatterers we take the spherical particles with the radius a_0. For such particles the shadow autocorrelation function has the following form[12]

$$F\,(\rho) = \begin{cases} \frac{2}{\pi}\left[\arccos\frac{\rho}{2a_0} - \frac{\rho}{2a_0}\sqrt{1-\left(\frac{\rho}{2a_0}\right)^2}\ \right] & \text{for } \rho = |\rho| \le 2a_0\ , \\ 0 & \text{for } \rho > 2a_0. \end{cases}$$

Having used Eqs. (9), (5), (6), (8), (14), and (15), for the mean intensity of the image we obtain

$$< I_t\,(l,\,\rho'') > \; = \; < I_t\,(l,\,\rho'') >_1 + < I_t\,(l,\,\rho'') >_2\ , \tag{16}$$

where

$$< I_t\,(l,\rho'') >_1 = \left(\frac{2}{\pi k l}\right)^2 \Omega\,\Omega_t^3 \int \mathrm{d}^2 t \int \mathrm{d}^2\rho \times$$

$$\times \exp\Bigg\{-\,\Omega_t\,\Omega^{-1}\,\varkappa\,\varkappa^*\,t^{\,2} - \varkappa_t\,\varkappa_t^*\,\rho^2 -$$

$$-\,2i\rho\hat{\rho}'' - 2\tau + \frac{\tau}{2}\int\limits_0^1 \mathrm{d}\xi\,[F\,(\,p\,(1-\xi)\,|\mathbf{t}|) +$$

$$+\,F(p(1-\xi)\,|\rho|)]\Bigg\}\ , \tag{17}$$

$$< I_t\,(l,\rho'') >_2 = \left(\frac{4}{\pi k l}\right)^2 \Omega^2\,\Omega_t^2 \times$$

$$\times \exp\left[-\,\frac{(1+\Omega_t\,/\Omega)\hat{\rho}''^2}{(1+\Omega_t\,/\Omega)^2 + \varkappa_t\,\varkappa_t^* - 1} - 2\tau\ \right] \times$$

$$\times \Bigg|(\varkappa^* + \Omega\,\Omega_t^{-1}\varkappa_t)^{-1}\int \mathrm{d}^2 t\,\exp\Bigg[-\,(\alpha + i\,\gamma)t^{\,2} -$$

$$-i(\beta - i\,\theta)\mathbf{t}\hat{\rho}'' + \frac{\tau}{2}\int\limits_0^1 \mathrm{d}\xi\ \ F\,(p\,(1-\xi)\,|\mathbf{t}|)\Bigg]\Bigg|^2\ , \tag{18}$$

$\Omega = ka^2/L$ and $\Omega_t = ka_t^2/L$ are the Fresnel numbers of the illuminating and receiving apertures, respectively. The transmission coefficient of the receiving aperture is taken in a Gaussian form with the effective radius a_t; $\varkappa = 1 + i\Omega(1 - L/F)$, $\varkappa_t = 1 + i\Omega_t(1 + L/l - L/F_t)$; $\hat{\rho}'' = \omega_0\,\rho''$, $\omega_0 = ka_t/l$;

$\alpha = 2p_1/N$; $\beta = 2p_2/M$; $\gamma = 2p_3/N$; $\theta = -\,\dfrac{2\Omega p_4}{\Omega_t\,M}$;

$N = p_1^2 + p_3^2$; $M = p_2^2 + p_4^2$, $p = a_t/a_0$, $p_1 = \Omega/(\Omega_t\varkappa\varkappa^*) + (\varkappa_t\,\varkappa_t^*)^{-1}$, $p_2 = 1 + \dfrac{\Omega[1 + (\varkappa - 1)(\varkappa_t - 1)]}{\Omega_t\varkappa\varkappa^*}$,

$p_3 = \dfrac{i(1 - \varkappa_t)}{\varkappa_t\varkappa_t^*} - \dfrac{i\Omega(1 - \varkappa)}{\Omega_t\varkappa\varkappa^*}$, $\quad p_4 = \dfrac{i(\varkappa + \varkappa_t - 2)]}{\varkappa\varkappa^*}$.

The first term in Eq. (16), $< I_t >_1$, describes the mean intensity distribution over the point object image on an uncorrelated path, the second one $< I_t >_2$ takes into account the correlation between the illuminating and reflected waves.

It follows from Eqs. (17) and (18) that in the lens focal plane ($l = F_t$), at the point $\rho'' = 0$ we have $< I_t\,(F_t,\,0) >_1 = < I_t\,(F_t,\,0) >_2$ under the condition of matching the receiving and illuminating apertures ($\Omega = \Omega_t$).[13]

The approximation (6) requires the condition $\tau > 1$ to be satisfied. Therefore, it is useful to analyze the obtained expression for $\tau \gg 1$. In this case we can use an approximate expression[14]

$$\exp\left[-\,\tau + \frac{\tau}{2}\int\limits_0^1 \mathrm{d}\xi\ F\,(p\,(1-\xi)\,|\mathbf{t}|)\right] \approx$$

$$\approx \exp(-\,\tau) + \exp\left[-\,\tau + \frac{\tau}{2}\int\limits_0^1 \mathrm{d}\xi\ F\,(p\,(1-\xi)\,|\mathbf{t}|)\right].$$

Then the first term in Eq. (16) can be presented in the form

$$< I_t\,(l,\rho'') >_1 = I_{\rm co}(l,\rho'') + I_{\rm inc}(l,\rho'')\ . \tag{19}$$

Here

$$I_{\rm co}(l,\rho'') = \left(\frac{2}{kl}\right)^2 \frac{\Omega^2\,\Omega_t^2}{|\varkappa|^2|\varkappa_t|^2}\exp\left[-\,2\tau - \frac{\hat{\rho}''^2}{\varkappa\varkappa_t}\right] \tag{20}$$

is the coherent component of the mean intensity distribution in the object image. This component has the same form as that in the case of a homogeneous medium except for Bouguer attenuation coefficient for the double path length $\mathrm{e}^{-2\tau}$. The incoherent component of the intensity distribution $I_{\rm inc}$ describes the image distortions due to multiple scattering of the wave by the discrete random inhomogeneities of a medium.

It is evident that the distribution width of the coherent component is determined by diffraction on the receiving telescope aperture and is

$$\delta_{\rm co} = \left[1 + \Omega_t^2\left(1 + \frac{L}{l} - \frac{L}{F_t}\right)^2\right]^{1/2} \omega_0^{-1}\ .$$

To estimate the distribution width of the incoherent component $I_{\rm inc}$, we used the approximation of the function $F\,(p\,(1-\xi)\left|\mathbf{t}\right|)$ in the form

$$F\,(p\,(1-\xi)\left|\mathbf{t}\right|) \approx \frac{1}{2}\exp\left[-4p^{\,2}(1-\xi)^2 t^{\,2}\right] .$$

Then for $I_{\rm inc}$ we have

$$I_{\rm inc}(l,\rho'') = \left(\frac{2}{kl}\right)^2 \times$$

$$\times \frac{\Omega\,\Omega_t^3}{\left(\Omega_t\,|\varkappa|^2/\Omega + \dfrac{2}{3}\,p^2\tau\right)\left(\varkappa\varkappa_t^* + \dfrac{2}{3}\,p^2\tau\right)} \times$$

$$\times \exp\left[-\tau - \frac{\omega_0^2\hat{\rho}''^2}{\varkappa\varkappa_t^* + \dfrac{2}{3}\,p^2\tau}\right], \qquad (21)$$

from which it follows that the distribution width of the incoherent component under the condition $p = a_t\,/\,a_0 \gg 1$ is

$$\delta_{\rm inc} \sim \left(\frac{2}{3}\,p^2\tau\right)^{1/2}\omega_0^{-1} \gg \delta_{\rm co}.$$

For the discrete scatterers whose characteristic dimensions are from 10^{-6} m to 10^{-3} m (clouds, fogs, hydrometeors etc.) the condition $p \gg 1$ is fulfilled practically always.

Thus, the mean intensity distribution over the image of a distant (point) object on the uncorrelated path consists of a narrow "peakB $I_{\rm co}(l,\,\rho'')$ of the width $\delta_{\rm co}$ and wide "pedestalB $I_{\rm inc}(l,\,\rho'')$ of the width $\delta_{\rm inc}$. Figure 1 depicts the results of calculation $< I_t\,(l,\,\rho'') >_1$ (curve *1*) for the concrete parameters of the transmitter–receiver and a medium by formulas (16)–(18). All values of the image mean intensity in the figure along the ordinate are normalized to the corresponding maximum values of the $< I_t\,(l,\,0) >_1$ at the point $\rho'' = 0$. It follows from the calculations by Eqs. (16)–(18) that relative contribution of the components $I_{\rm co}$ and $I_{\rm inc}$ into the mean intensity $< I_t\,(l,\,\rho'') >_1$ varies depending on the optical thickness τ. So, Figures 1*b* and *c* show (curve *1*) that at $\tau = 5$ the intensity $< I_t\,(l,\,\rho'') >_1$ practically coincides with its coherent component $I_{\rm co}(l,\,\rho'')$ and contribution of $I_{\rm inc}$ equals zero (Fig. 1*b*), at the same time for $\tau = 25$ (Fig. 1*c*) the main contribution into $< I_t\,(l,\,\rho'') >_1$ comes from the component $I_{\rm inc}(l,\,\rho'')$.

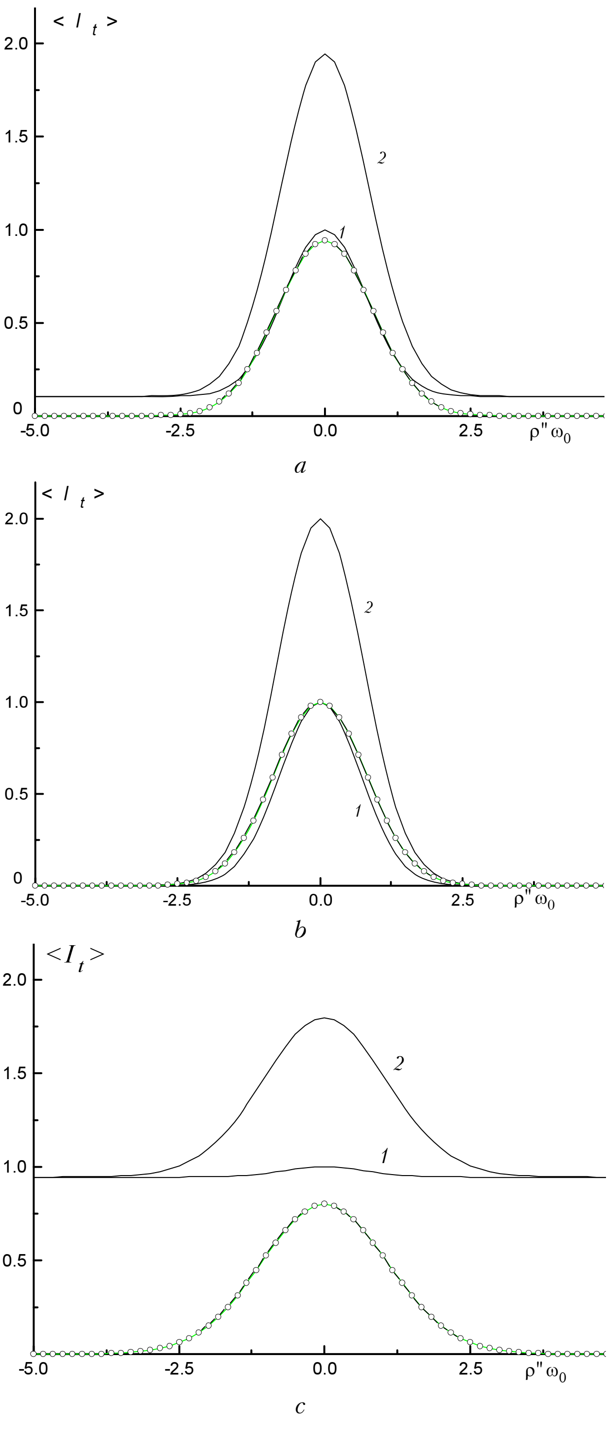

FIG. 1. Intensity distribution over the image of the point object in the plane $1 + \dfrac{L}{l} - \dfrac{L}{F_t} = 0$ *for* $\Omega = \Omega_t = 1$, $p = 100$, $\tau = 15$ (*a*), $\tau = 5$ (*b*), $\tau = 25$ (*c*).

Contribution of the term $< I_t (l, \rho'') >_2$ into the intensity distribution of a point object responsible for the correlation between the illuminating and reflecting waves is shown in Figure 1 by curves with open circles. It is clear from this curves that width of the distribution $< I_t (l, \rho'') >_2$ is of the order of δ_{co}. Maximum amplitude $< I_t (l, 0) >_2$ for small optical thickness (Figs. 1*a*,*b*) is comparable to and for large optical thickness (Fig. 1*c*) essentially exceeds the amplitude of the coherent component of the image intensity for the case of uncorrelated path. The total intensity of the image of a point object on a correlated path $< I_t (l, \rho'') >$ is depicted in Fig. 1 by curves *2*.

Thus, the counter wave correlation leads to "enhancementB of the coherent component of the distant object image in a discrete random medium. This increases the contrast of images and can allow us to observe objects in turbid media which are indistinguishable without illumination or with lateral illumination when no correlation between the incident and reflected waves occurs.

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