Study of the formation and propagation of contour beams of a given shape

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Introduction

Structured laser beams have shown their effectiveness in the problem of optical trapping and micromanipulation [1], as well as in laser processing and structuring of materials [2]. Beams in the form of light curves are of particular interest, since they provide amplification of the acting optical forces [3] in a narrow region of intensity concentration.

The analytical formalism in the analysis of beams with a spatial spectrum in the form of thin curves is associated with the possibility of reducing the propagation operator of such beams to a one-dimensional Whittaker integral [4].

We study the influence of various parameters on the formation and propagation of contour beams of a given shape using the Whittaker integral, as well as the Fresnel transform based on the fast Fourier transform in this paper.

Formation and propagation of beams

The Whittaker integral is defined by the formula [4]:

$$E(x,y)=\int_0^T w(t)\cdot e^{\left(-i\cdot\frac{2\pi}{\lambda f_0}\right)\cdot R(t)\cdot(x\cdot\cos(t)+y\cdot\sin(t))}dt, \qquad (1)$$

where E(x,y) is spatial spectrum of a given curve; λ is wavelength of radiation; f_0 is focal length of the lens; w(t) is a parametric function describing the distribution on the curve; R(t) is a parametric function describing the shape of the curve [4].

When studying the formation and propagation of beams with a spatial spectrum in the form of parametric curves, the fast Fourier transform (FFT) and the Fresnel transform based on the FFT are used.

It should be noted that the Fresnel transform can be an expansion in parabolic waves. The Fresnel and Fourier transforms interact with each other if decomposed the Fresnel kernel.

We conclude that the Fresnel transform can be implemented through the Fourier using the following formula:

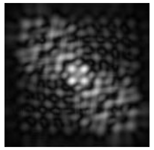
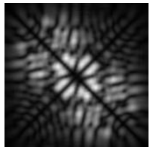
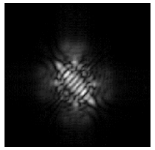
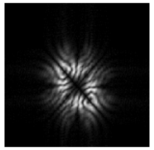
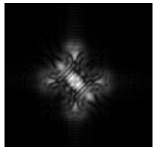
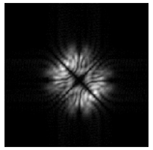
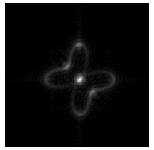
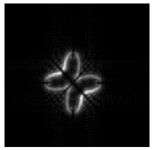
$$F(u,v,z)=\mathbb{F}\left\{E(x,y)\cdot e^{\frac{ik}{2z}\left(x^2+y^2\right)}\right\}, \qquad (2)$$

where symbol corresponds to the FFT operator; z is the beam propagation distance.

The results of modelling the propagation of contour beams in free space, obtained using the Fresnel transform, are shown in Table I. It can be seen that at large distances (z=5000 mm) distributions corresponding to the given curves are formed.

When observing beam emission in free space, it can be noted that they are diffraction-free.

TABLE I. BEAM PROPAGATION ATT VARIOUS Z (BUTTERFLY)

	Amplitude after Fresnel at w(t)=1	Amplitude after Fresnel at w(t)=sin(4t)
z= 100 mm		
z= 800 mm		
z= 1500 mm		
z= 5000 mm		

The influence of w(t) significantly changes the picture of the obtained curves, not only in the far zone, but also in the near one. It can be seen from the Table I that, indeed, at z from the near zone, their appearance changes significantly during propagation.

Complex curves, such as a butterfly change their structures significantly when emitted, while simpler ones retain some symmetry. Thus, we can come to the following conclusion that such curves are envelopes.

Conclusion

A study was made of the influence of various parameters on the formation and propagation of contour beams of a given shape. Difference in the results obtained using the Whittaker integral and the FFT is due to the peculiarities of the numerical calculation. In particular, the FFT requires recalculation of two-dimensional arrays, while the calculation of the Whittaker integral involves the use of a one-dimensional array, which provides a comparable calculation time with a much larger number of samples. Simulation of beam propagation in free space using the Fresnel transform confirmed the formation of distributions corresponding to given curves at large distances.

References

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