PROJECTION METHOD FOR VISUALIZING THE SPATIAL STRUCTURE OF LIGHT BEAMS USING A NEGATIVE LENS

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Abstract

A simple projection method for direct visualization of the transverse spatial structure of freely propagating light beams is proposed and experimentally demonstrated. The optical arrangement consists of a negative lens positioned downstream of the investigated beam cross section and a remote observation screen. Within the paraxial approximation, the lens converts the transverse field distribution into an angular distribution that is projected onto the screen with a magnification determined by the ratio

$$M = \frac{L}{|f|},$$

where L is the distance from the lens to the screen and f is the focal length of the negative lens.

The method enables non-invasive observation of beam cross sections while preserving unrestricted access to the investigated region. Longitudinal scanning is achieved simply by translating the lens along the propagation axis, allowing the spatial evolution of optical fields to be monitored without modifying the experimental arrangement.

The technique has been applied to visualization of the fine spatial structure of semiconductor laser beams and to the investigation of diffraction fields generated by a knife edge. Experiments performed with projection magnifications of approximately $M \approx 300$ reveal structural details that remain inaccessible under conventional observation conditions.

Owing to its simplicity, low cost, and high visual sensitivity, the proposed method represents a useful experimental tool for exploratory studies of wave-optical phenomena, laser beam diagnostics, and educational laboratory demonstrations.

1 INTRODUCTION

Direct observation of the spatial structure of optical fields in the near-diffraction region and in the immediate vicinity of diffracting objects remains experimentally challenging. Placing a detector or observation screen directly within the region of interest inevitably perturbs the propagating field and is often prohibited by the geometry of the optical arrangement.

Near-field scanning techniques provide access to local field distributions with subwavelength resolution; however, they require specialized instrumentation and are primarily intended for investigations of localized electromagnetic fields near surfaces. Their application to freely propagating laser beams is therefore limited.

Conventional optical measurements employing a distant observation screen record only the intensity distribution formed in the observation plane. They provide little or no information about the spatial evolution of the field between the diffracting object and the detector. Consequently, experimental investigation of beam transformation, diffraction development, and interference-field formation within intermediate cross sections becomes considerably more difficult.

The present work introduces a projection method based on a negative lens positioned downstream of the investigated beam cross section. The method enables direct visualization of the transverse structure of an arbitrarily selected section of a freely propagating beam while leaving the investigated region completely unobstructed.

Unlike near-field scanning methods, the proposed technique employs only conventional optical components and requires neither scanning probes nor computational field reconstruction. The beam cross section is projected onto a remote observation screen with substantial magnification, allowing structural details that are normally inaccessible to direct visual inspection to become observable.

An additional advantage of the method is the possibility of longitudinal scanning. Translating the negative lens along the propagation axis makes it possible to observe consecutive beam cross sections without modifying the remaining optical arrangement. This permits direct visualization of the spatial evolution of diffraction and interference structures in real time.

The method was originally developed as an experimental tool for investigating the formation and evolution of diffraction patterns in free space. However, the experiments presented below demonstrate that its applicability extends beyond diffraction studies to include laser-beam diagnostics, visualization of fine spatial beam structure, and educational demonstrations in wave optics.

2 PRINCIPLE OF THE METHOD

The experimental arrangement consists of a negative lens with focal length $f < 0$ positioned downstream of the beam cross section under investigation and an observation screen located at a distance $L \gg |f|$ from the lens (Fig. 1).

The position of the negative lens is not fixed and may be varied freely along the propagation axis, allowing arbitrary transverse beam cross sections to be selected for observation without disturbing the investigated optical field.

Within the paraxial approximation, a ray passing through the lens at a transverse coordinate r is deflected by an angle

$$\theta \approx -\frac{r}{|f|}. \tag{1}$$

After propagating over the distance L, the corresponding displacement on the observation screen is

$$R = L\theta. \tag{2}$$

Substituting Eq. (1) into Eq. (2) yields

$$R \approx -\frac{L}{|f|} r, \tag{3}$$

which immediately gives the projection magnification

$$M = \frac{L}{|f|}. \tag{4}$$

For a typical experimental configuration with $L = 15$ m and $f = -50$ mm, the projection magnification is

$$M = 300.$$

Consequently, structural features having characteristic dimensions of approximately 100 μm are projected into images about 3 cm in size, making them readily observable by eye and easily recorded using an ordinary digital camera.

For weakly divergent laser beams the projected image closely reproduces the transverse intensity distribution existing in the selected beam cross section. If the wavefront possesses noticeable curvature, the projection represents the corresponding angular distribution of the optical field. Although the image no longer corresponds to a strict geometrical magnification of the cross section, it still contains valuable information about the spatial organization and evolution of the beam. An important feature of the proposed method is that the observation plane is not fixed by the optical arrangement. The negative lens may be positioned at essentially any location downstream of the selected beam cross section. Consequently, any transverse section of a freely propagating beam can be visualized simply by translating the lens along the propagation axis, without introducing any optical element into the investigated region or modifying the remainder of the experimental setup.

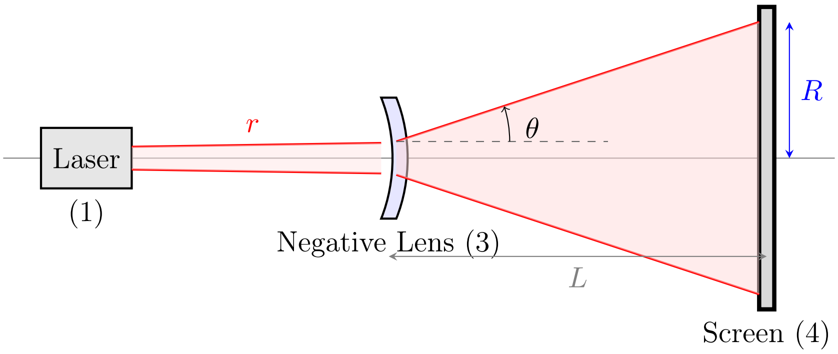

Figure 1: Principle of the beam projection and magnification using a negative lens.

The principal advantages of the proposed method are summarized below.

- **Non-invasive observation.** No detector or observation screen is introduced into the investigated region, thereby preserving the original optical field.
- **Adjustable projection magnification.** The magnification is determined solely by the ratio $L/|f|$ and can be varied over a wide range by selecting an appropriate lens and observation distance.

- **Real-time visualization.** The spatial structure of the beam is observed directly without numerical reconstruction or digital image processing.
- **Longitudinal scanning.** Translation of the negative lens along the propagation axis enables successive beam cross sections to be visualized while leaving the remaining optical arrangement unchanged.

3 EXPERIMENTAL DEMONSTRATION

3.1 Visualization of the Internal Structure of a Laser Beam

The proposed projection method was first applied to the investigation of the spatial structure of semiconductor laser radiation.

Experiments were performed using a red semiconductor laser operating at a wavelength of

$$\lambda = 650 \text{ nm}.$$

The projection system consisted of a negative lens with a focal length of $f = -50$ mm and a remote observation screen positioned at a distance of $L = 15$ m, corresponding to a projection magnification of approximately

$$M \approx 300.$$

Under these conditions the projected image revealed numerous structural features that remain practically invisible during conventional observation of the beam.

The recorded intensity distribution exhibited pronounced spatial inhomogeneity together with a complex fine-scale texture extending across the beam cross section. Characteristic dimensions of individual structural elements were estimated to be on the order of several tens of micrometres in the original beam.

In addition, concentric interference rings and layered intensity modulations were observed. These features are consistent with optical artifacts originating from multiple reflections within the protective window and with non-uniform emission across the semiconductor laser aperture. Although the precise origin of each individual feature was not investigated in the present work, the experiments demonstrate that the projection method possesses sufficient spatial sensitivity to reveal fine-scale imperfections of practical laser sources.

Figure 2: Projection image of the transverse structure of a low-quality semiconductor laser beam obtained with a projection magnification of approximately $M = 300$. The image reveals pronounced spatial inhomogeneity, concentric interference rings, and fine layered intensity modulation that are essentially invisible under ordinary observation conditions.

The experiments demonstrate that the proposed method can also serve as a simple non-contact diagnostic tool for qualitative evaluation of laser beam quality. Since the original beam remains undisturbed throughout the measurement, the method may be particularly useful for rapid alignment, educational demonstrations, and exploratory investigations of laser sources.

3.2 Diffraction Field Behind a Knife Edge

The second series of experiments was devoted to visualization of the diffraction field generated by an opaque knife edge.

The projection system was translated along the propagation axis, allowing successive cross sections of the diffraction field to be observed over the distance range from approximately 0 to 20 cm behind the diffracting edge.

The projected images revealed the gradual spatial evolution of the diffraction pattern immediately after the obstacle. Alternating bright and dark regions formed a distinct layered structure whose geometry changed continuously with increasing propagation distance.

Unlike conventional observation methods, the proposed technique makes it possible to investigate these intermediate field distributions without introducing an observation screen directly into the diffraction region. Consequently, unrestricted experimental access to the investigated space is preserved throughout the measurements.

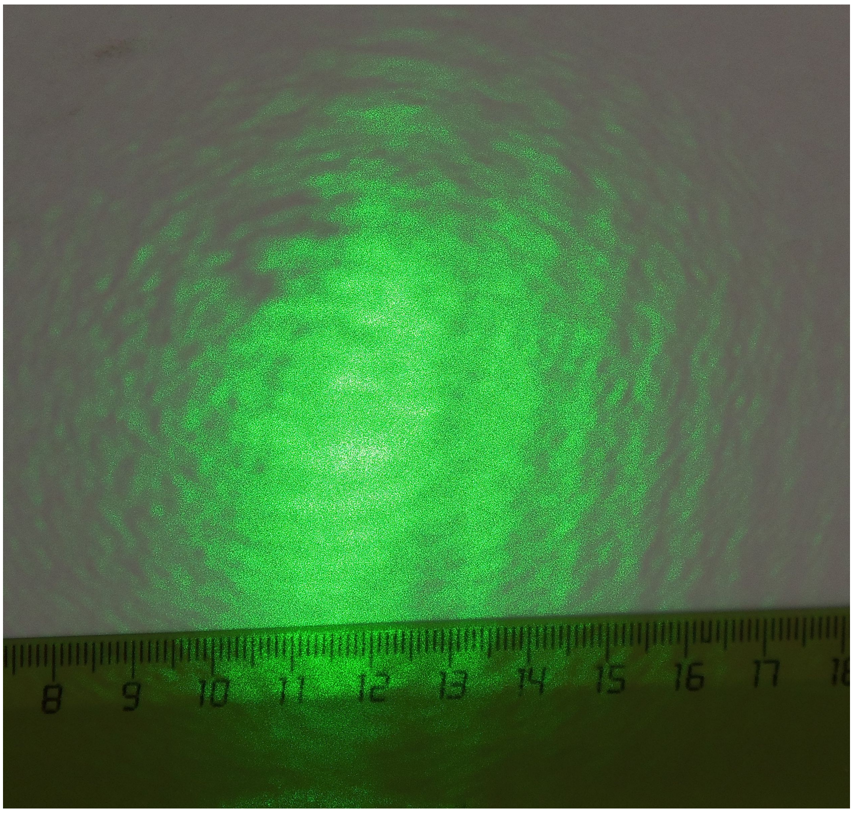

Figure 3: Projection image of the beam cross section recorded in the impact-parameter region during diffraction by an opaque knife edge. The photograph illustrates the layered spatial modulation of the optical field and demonstrates the capability of the projection method to visualize the evolution of diffraction structures in the near-field region.

The experiments confirm that the proposed projection method provides direct access to the spatial evolution of diffraction fields in regions where conventional observation techniques are difficult or impossible to apply.

4 CONCLUSION

A projection method for direct visualization of the spatial structure of freely propagating light beams using a negative lens has been proposed and experimentally demonstrated.

The method combines a simple optical arrangement with high visualization efficiency and provides several practical advantages:

- direct observation of arbitrarily selected beam cross sections;
- projection magnification determined by the simple relationship

$$M = \frac{L}{|f|};$$

- completely non-invasive measurements, preserving unrestricted access to the investigated optical field;
- real-time visualization without numerical reconstruction or digital image processing;

- longitudinal scanning of the optical field through simple translation of the negative lens along the propagation axis.

Experimental investigations have demonstrated the capability of the method to reveal the fine spatial structure of semiconductor laser beams and to visualize the evolution of diffraction fields generated by a knife edge. Projection magnifications of approximately $M \approx 300$ make structural details of the order of several tens of micrometres directly observable on a remote screen.

Beyond its application as a visualization technique, the method may also serve as a convenient tool for qualitative laser-beam diagnostics, alignment of optical systems, exploratory investigations of diffraction phenomena, and educational laboratory demonstrations.

The simplicity of the optical arrangement, together with the absence of mechanical scanning devices and computational image reconstruction, makes the proposed approach readily applicable in both research laboratories and teaching environments.

Unlike conventional screen-based observation, the proposed projection method allows virtually any beam cross section to be selected for visualization while preserving unrestricted access to the investigated optical field. This flexibility makes the technique particularly suitable for exploratory investigations of beam evolution and diffraction phenomena. Future work will focus on systematic investigation of the spatial evolution of diffraction structures, visualization of optical fields produced by various diffracting objects, and quantitative characterization of beam structure using projection measurements.

References

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