# Lensless Object Detection and Positioning via Coherence Measurement

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**Abstract:** We measure the complex-coherence function of incoherent light scattered by a one-dimensional object in various configurations and determine the axial and transverse position of the object and its size by examining only the coherence function.
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Coherence is a universal wave phenomenon, which describes the similarities or correlation of waves, typically, at two points in space or time [1]. Measurements of complex-coherence function can be carried out in alternative methods and the example settings include but not limited to Mach-Zehnder interferometer, Michelson interferometer, and Young's double slit experiment [2]. The complex-coherence function is dependent on many variables such as the propagation distance, the source characteristics, perturbation in the medium. Each of these effects can be accounted for in a careful analysis of the measured complex-coherence function. In other words, each type of perturbation to the electromagnetic field leaves its own fingerprint on the complex-coherence function.

Here, we show measurements of complex-coherence function of a light field, that is incoherent both spatially and temporally, scattered through one-dimensional (1D) objects in various configurations with respect to the source. By the measurements, which is achieved via Young's double slit experiment [3,4] by using a computer-controlled digital-micro-mirror device [5,6], we obtain object's size, axial and transverse coordinates with respect to the source position [7]. With this measurement method, we target a detection scheme where the objects are around a corner and hidden from direct sight [8].

The concept of retrieving the complex-coherence function is depicted in Fig. 1. To obtain the complex-coherence function as a function of spatial separation, one needs to measure the relative phase at every pair of points in space and the corresponding amplitudes, which is readily achieved by measuring the shift of the interference pattern from the pair of points and the amplitudes from two single slits, respectively. In the actual experiment, the slits are realized in reflection mode via digital micromirror device (DMD, Texas Instruments DLP6500) and to produce the interference patterns the Fourier transform is realized with a spherical lens after a pair of lenses used for optical relay (and spatial filtering), which are omitted in the schematic in Fig. 1(a) for simplicity.

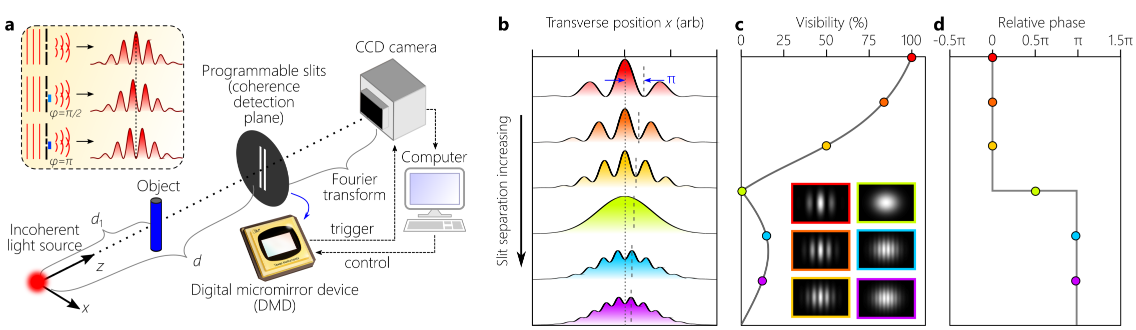


Fig. 1. The concept of the complex-coherence measurement. (a) The schematic of the experimental setup where an incoherent source with 1 nm bandwidth and center wavelength of 630 nm passes through a one-dimensional (1D) object and reflects from the computer-controlled double slits (here shown in transmission for simplicity). Then, spatial Fourier transform is implemented (see text for the details). The inset depicts the effect of relative phase for spatially coherent fields. (b) Spatially and spectrally partially-coherent light produces interference patterns with different visibilities depending on the separation of double slits, the spectral bandwidth and the interaction of the propagating field with the object along the propagation path. (c) The visibilities obtained from the interference patterns are proportional to the coherence properties of the field. The insets show ideal 2D interference patterns. (d) Extraction of the relative phase for different slit separations (based on the shift of the interference patterns) enables to retrieve the complex-coherence function.

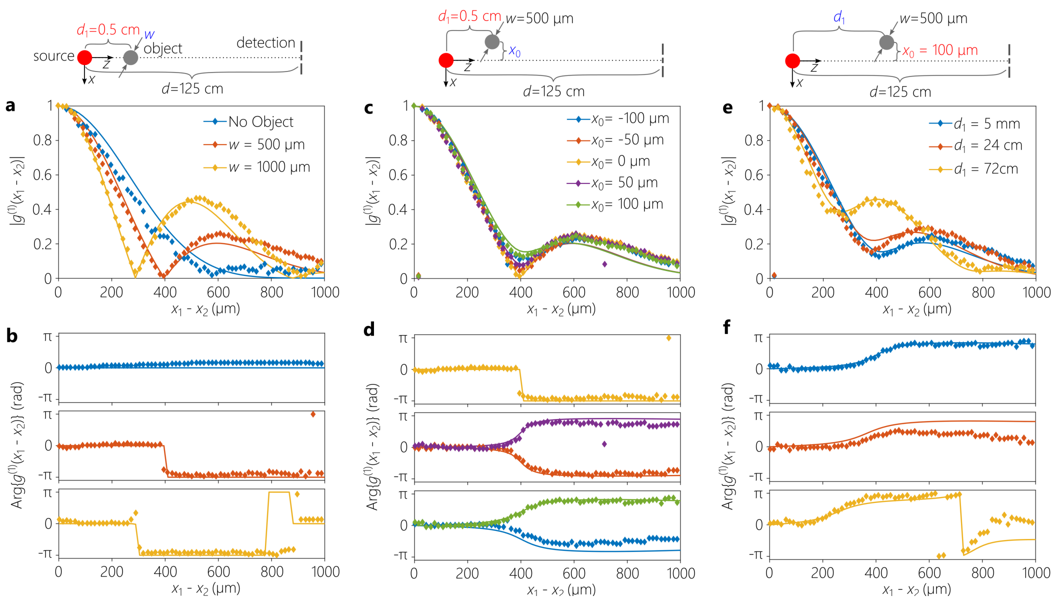


Fig. 2. The effect of object's size, axial position and transverse position on the complex-coherence function $g^{(1)}(x_1 - x_2)$. (a) The magnitude and (b) phase of the coherence function for two object widths and no object case. (c,d) Same as in (a,b) except for various transverse positions. (e,f) Same as in (a,b) except for various source to object distances. (a-f) The numerical simulations are given by solid lines.

In the cases reported here, we give the magnitude and phase of the normalized second-order field correlation as a function of slit separation given by $g^{(1)}(x_1 - x_2) = \langle E^*(x_1)E(x_2)\rangle / \langle\sqrt{I(x_1)I(x_2)}\rangle$, where $E(x_1)$ is the field at $x_1$, $I(x_1)$ is the corresponding intensity, and $\langle\ \rangle$ is for the averaging inherent in the measurement of the scattered LED source via a slow detector, i.e., a CCD camera in our case.

First, we consider a scattering object located at $x = 0$ for two object sizes, $w = 500$ and 1000 $\mu$m, and compare the cases to the absence of the object [Fig. 2(a) and 2(b)]. While in the absence of the object, there is no clear signature in the magnitude of $g^{(1)}$ and phase, the object reveals its signatures depending on its size clearly in the first minimum of the coherence function and $\pi$-phase shift. Next, we consider the case for which the objects transverse position is varied [Fig. 2(c) and 2(d)]. In this case, we see a different signature in the amplitude of the coherence function and phase transitions. When the object is offset from the center, the amplitude does not go to zero at its first minimum point. Moreover, this feature is accompanied by the smooth phase transitions. Even though there is arbitrariness in the amplitude function to determine the sign of the transverse position, the arbitrariness is removed by looking at the sign of the phase. Finally, we look at the effect of the distance from the source to the object [Fig. 2(e) and 2(f)] for a fixed transverse position ($x_0 = 100\ \mu m$). Since the object is not transversely centered, all of the transitions are smooth. In this case, the tell-tale sign is the position of the first minimum as in the first case. In this case, however, it's important to observe the second minimum points as well.

In conclusion, by measuring complex-coherence function through digitally implemented double-slit experiments, we showed the effect of an object intercepting an incoherent light source and the fingerprints of its size and position on the coherence function.

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