Detecting the Presence of a Transparent Object in Off-Axis Digital Holograms

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Abstract: Detecting presence of an object in digital holograms is an important consideration in many applications. We propose a novel method that works directly in the hologram plane to determine the presence or absence of an object.

1. Introduction

A hologram, H, is an interference pattern of an object wave, O, and a reference wave, R, as $H = |R|^2 + |O|^2 + RO^* + R^*O$ where $|R|^2$ and $|O|^2$ are the object and reference intensities, respectively [1]. These two first terms together constitute the dc term that contains low-frequency components located spatially at the center of the Fourier domain. When applying holography to microscopy, digital holographic microscopy (DHM), the object wave can be magnified using a microscope objective, and an off-axis configuration enables efficient filtering of unwanted terms allowing one to reconstruct only the primary image [2]. The numerical reconstruction contains both intensity and quantitative phase information of the imaged object.

Several approaches have been proposed to determine the in-focus-depth of a transparent object [3,4]. However, each of these methods assumes that the hologram contains an object in its field of view (FOV). Furthermore, well-known techniques to segment a transparent object from a hologram reconstruction volume (one approach that as a side-effect can detect the presence or absence of object) requires multiple reconstruction steps per hologram. Although straightforward to solve for reflective objects, efficiently detecting the presence or absence of a transparent object of interest in a noisy medium can be challenging.

When DHM is used for time-lapse imaging, particle field imaging, or any other application where a large number of holograms are captured, many holograms can be recorded without an object in their field of view (FOV). Subsequently processing these holograms as if they contained objects can be wasteful. To overcome this inefficiency, we propose an algorithm that can be used to detect the presence, or alternatively absence, of a transparent object in the FOV before any numerical processing on a captured digital hologram is performed, including for example searching for the in-focus plane.

We propose a histogram-based approach to quantify gross features in the Fourier domain of digital holograms. The metric to determine low frequency content of a hologram is derived as

$$\alpha = \frac{1}{mn} \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} \Omega(x,y)\,, \tag{1}$$

where Ω is a $m \times n$ binary mask containing ones in the region covering half of the dc term if they have values above a threshold defined as

$$\Omega(x,y) = \begin{cases} 1, & \text{if } H'(x+u, y+v) > \tau \\ 0, & \text{otherwise}\,, \end{cases} \tag{2}$$

where $x \in [0, m-1]$, $y \in [0, n-1]$, and

$$u = \frac{M}{2}, \quad v = \frac{5}{16}N\,. \tag{3}$$

H' is the amplitude of the two-dimensional Fourier transform of a M×N pixel hologram.

2. Results

Experimental results from 580 holograms (290 with and 290 without an object in FOV) are shown in Fig. 1. The proposed metric was compared with intensity, variance, and Tamura coefficient, which have been reported before as metrics for finding in-focus planes of digital holograms. For the intensity calculation, hologram plane intensities were summed. The Tamura coefficient, C, was calculated as described in [3]. Because the metric requires a hyperparameter that might need to be tuned to the application at hand, the metric was also compared, on the basis of accuracy and computational efficiency, with approaches employing well-known deep learning convolutional neural networks as binary classifiers, trained separately on hologram-domain and Fourier-domain inputs.

It can be observed from these results that the proposed method can be used to efficiently detect the presence or absence of an object with high reliability (see Fig. 1d). Intensity and variance are not suitable to detect the presence of an object as can be deduced from Fig. 1a-b. The Tamura coefficient works to some extent (Fig. 1c).

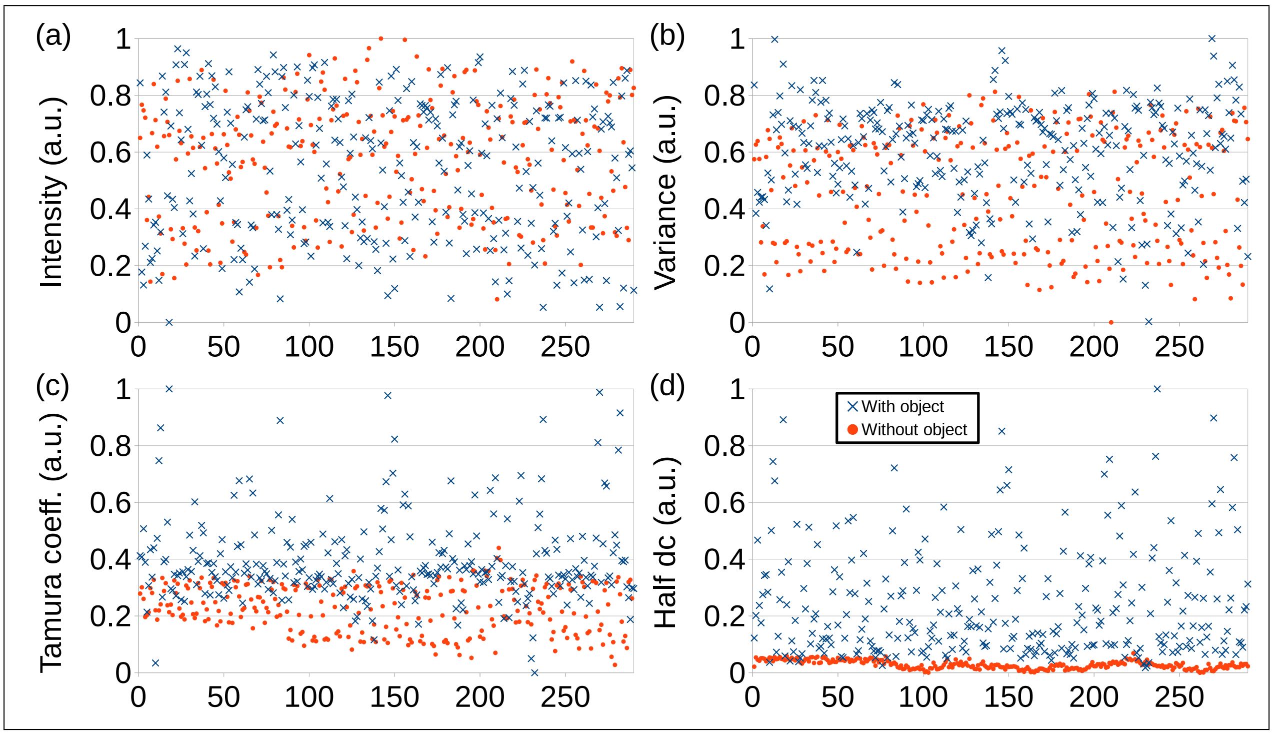

Fig. 1. Experimental results: (a) intensity, (b) variance, (c) Tamura coefficient, (d) our approach using metric α as defined in the body of the summary. All values are normalized between 0 and 1. The horizontal axis in each case represents trial number.

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