# 3D Object Detection in Digital Holographic Microscope Images

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## I. Introduction

Digital Holographic Microscopy (DHM) is based on the classical holographic principle invented by Hungarian physicist Dennis Gabor. The images are acquired by a CCD camera and depth slices are reconstructed and processed using General Purpose Graphical Processor Units (GPGPU). The optical setup is demonstrated in Fig. 1.

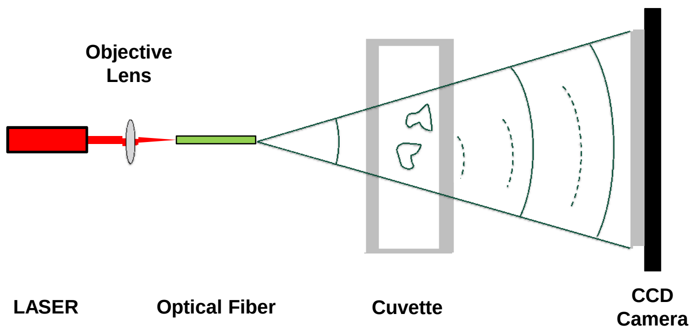


**Figure 1.** Inline DHM optical setup. 635 nm LASER was used in the experiments. The pinhole was replaced with a single mode optical fiber with 6 µm diamater, resulting a 0.5 µm lateral resolution.

## II. Numerical Diffraction

In holographic images the depth information is globally coded. There are three well known methods for holographic reconstruction: Angular spectrum, Huygens convolution, and Fresnel transform. We have implemented the angular spectrum method because its numerical stability and complexity. It requires only one Fourier transform for each slice, plus an additional one for the input image. The hologram captured by the CCD can be described by Eq. 1.

$$|H|^2 = |O|^2 + |R|^2 + |O|^* R + |R|^* O \qquad (1)$$

The Fourier transformation of the image is defined by Eq 2.

$$A(k_x, k_y, k_{z=0}) = \iint E_0(x_0, y_0, 0)\, e^{(-i(k_x x_0 + k_y y_0))}\, dx_0\, dy_0 \qquad (2)$$

A reconstruction at depth z can be calculated according to Eq. 3 followed by an inverse Fourier transform (Eq. 4).

$$A(k_x, k_y, z) = A(k_x, k_y, z = 0) e^{-izk_z} \qquad (3)$$

$$E(x, y, z) = \iint A(k_x, k_y, z)\, e^{(-i(xk_x + yk_y))}\, dx\, dy \qquad (4)$$

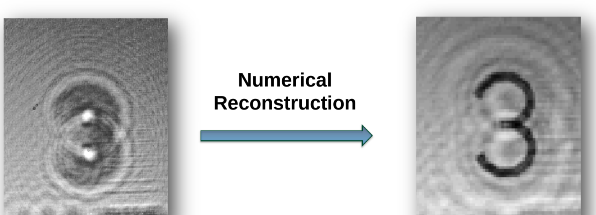


**Figure 2.** Left: Captured holographic image by the CCD camera. Right: Reconstructed image at the focal plane (220 µm).

## III. Algorithmic Framework

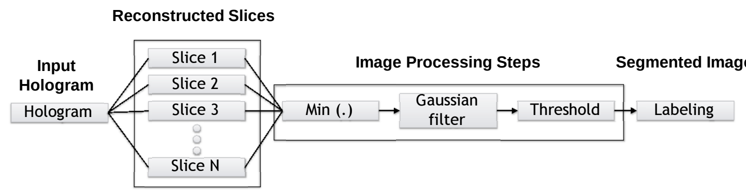


**Figure 3.** Algorithm overview showing each step of detection process. A total of 100 slices were used in the experiments.

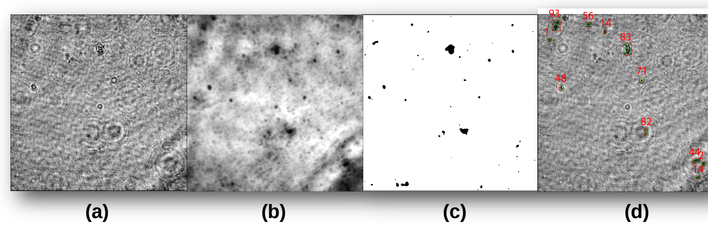


**Figure 4.** (a) Input hologram image, (b) after min(.) step, (c) binarized image, (d) object detection result.

## IV. Results

The algorithm was tested on 512x512 size images. The 100 reconstruction kernels were calculated off-line and transferred to the main memory of the video card. The Fourier transform was done using the CUFFT 3.1 library.

**Table I: Summary of processing times in milliseconds for each step of the algorithm.**

| | Intel CPU | NVIDIA Video Card | | |
|---|---|---|---|---|
| | Q9300 | GT 240 | 9800 GT | GTX 280 |
| Host to Device | NA | 1.35 | 1.28 | 1.38 |
| Device to Host | NA | 1.82 | 1.55 | 1.64 |
| 2D Complex FFT | 7.05 | 0.86 | 0.54 | 0.34 |
| 2D Complex IFFT | 838.00 | 67.00 | 40.00 | 24.00 |
| Complex Multiplication | 196.00 | 35.00 | 20.00 | 12.00 |
| Min | 200.00 | 20.79 | 11.88 | 8.91 |
| Gaussian Filter | 6.28 | 4.12 | 4.15 | 4.00 |
| Threshold | 0.54 | 0.18 | 0.10 | 0.06 |
| Total Time: [ms] | 1247.87 | 131.12 | 79.50 | 52.33 |
| Frame Rate [1/s]: | 0.80 | 7.63 | 12.58 | 19.11 |

We achieved a **24x** total speed up using the GTX 280 video card. This enables real-time holographic reconstruction and object detection in volumetric data.

## Acknowledgement

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