LAGRANGIAN PARTICLE TRACKING IN ISOTROPIC TURBULENT FLOW VIA HOLOGRAPHIC AND INTENSITY BASED STEREOSCOPY

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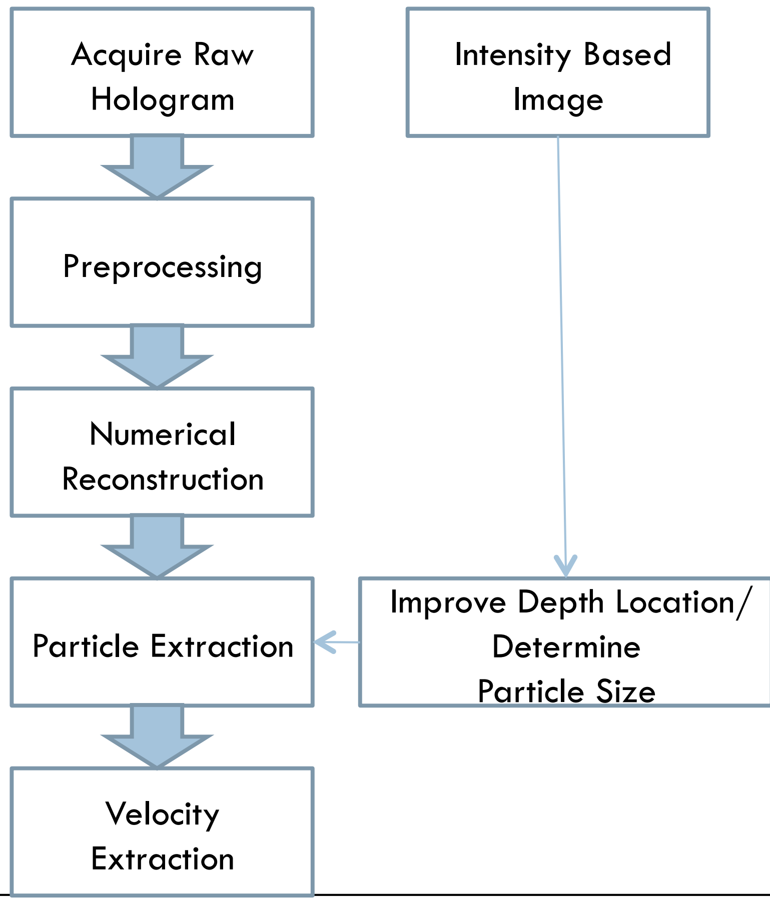
Outline

Holography

- Concept of using a wave front imaging to do a three dimensional reconstruction first introduced by (Gabor,1949)
- After introduction of the laser in the 1960's did holography really start to flourish(Collier ,1971;Vikram,1992).

I. Film Based Holography
   A. Intensity only reconstruction
   B. Time consuming to reconstruct Holograms from Film
II. Digital Holography
   A. Easier acquisition of Data analysis (Intensity as well as complex amplitude)
   B. Resolution restricted due to angular aperture as well as size

Digital holographic Process



Matlab image processing toolbox

1. Subtract Background Image

2. Region building base on connectivity relationships between adjacent foreground pixels in three dimensions (DeJong,2008)

3. Contrast-limited adaptive histogram equalization

Based on Huygens Principle which states that ... known ... any other ...

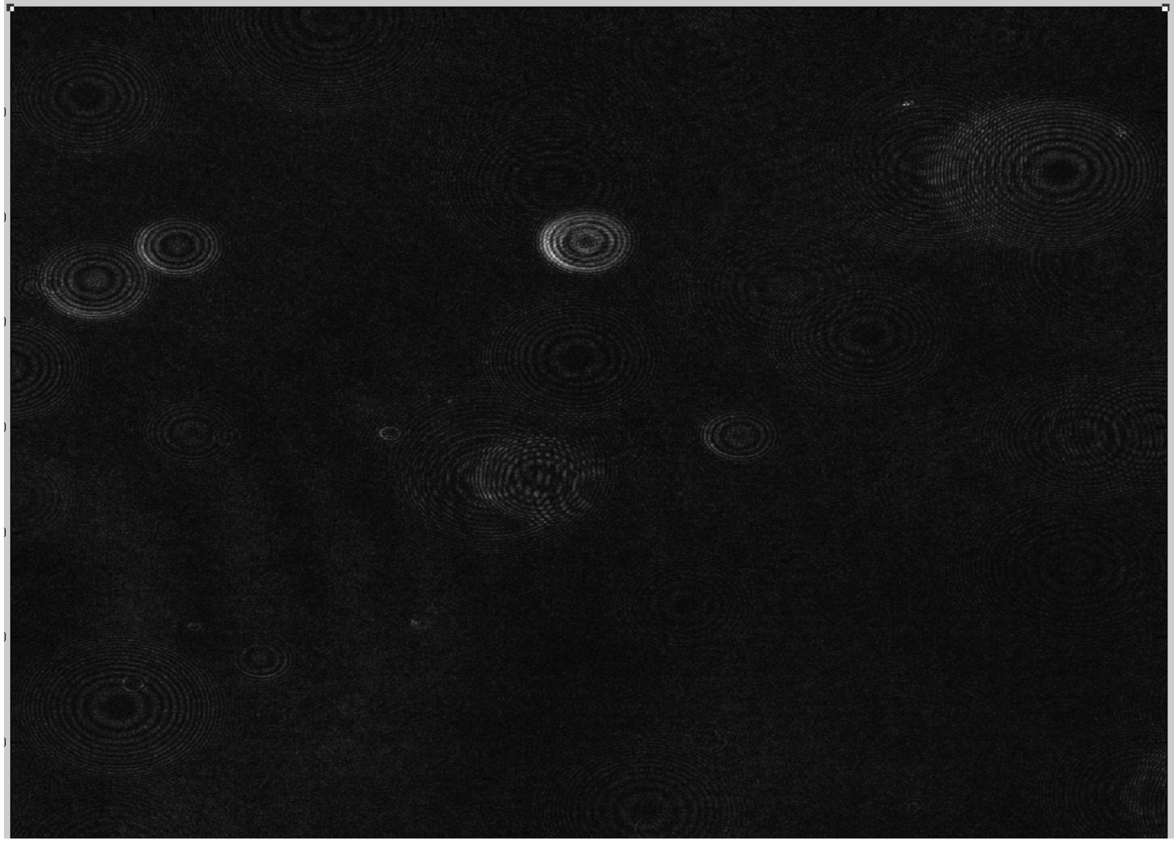
- Particle ... Window Filter
- Optical Sectioning
  - 3D image
  - Off axis (our group)
- Nearest Neighbor
- Particle Relaxation Method

Rayleigh-Sommerfeld diffraction theory

$$= \iint I_H(\xi,\eta) R(\xi,\eta) \frac{\exp(jk\rho)}{j\lambda\rho} d\xi d\eta$$

(use Fourier Transform)

Raw Hologram



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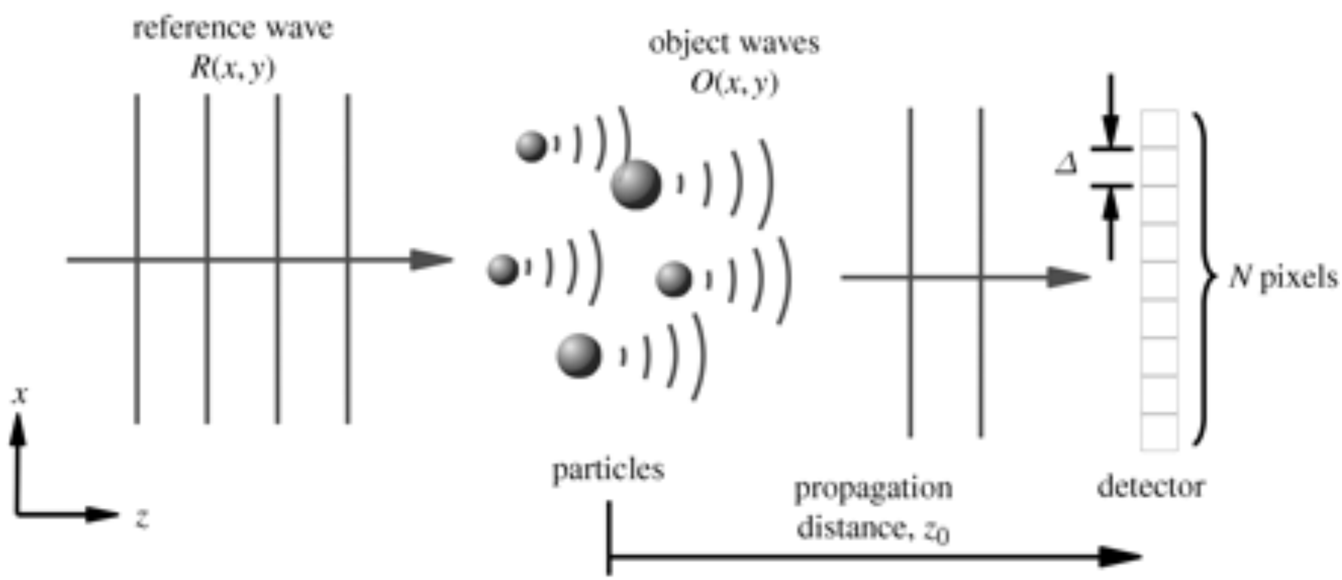
Raw Hologram Acquisition



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Angular Aperture

- angular aperture is a function of the camera pixel size, Δ, and the image size, a function of the number of pixels, *N*. Given the system parameters: ,

$$\Omega = \begin{cases} \frac{H}{2z} & if\, \Delta \le \Delta_c \\ \frac{\lambda}{2\Delta} & if\, \Delta \ge \Delta_c \end{cases}$$

Critical Pixel Size: $\Delta_C = \lambda z / H = \sqrt{\lambda z / N}$

- Our CCD camera is 2650x2650 pixels with an effective pixel size of 2 micrometers with a long distance microscopic lens system

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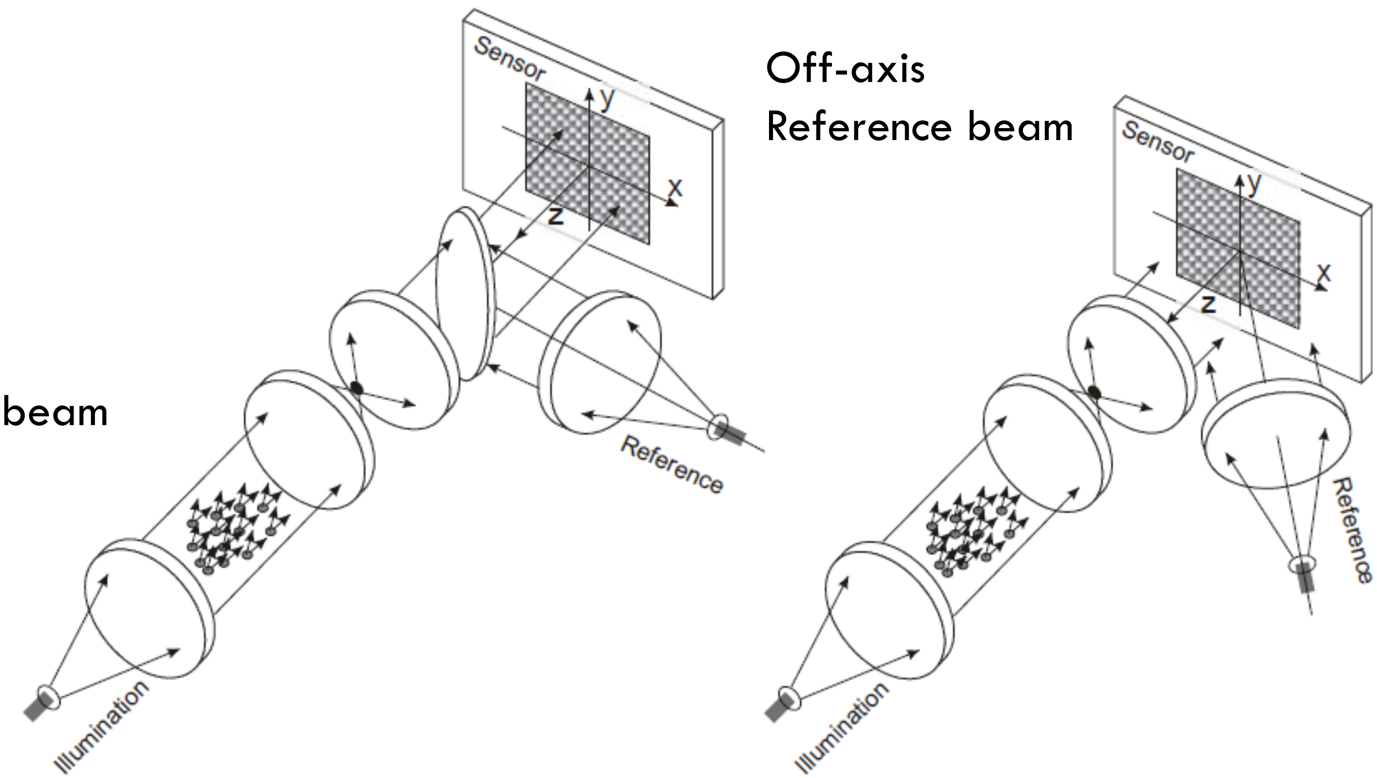
In-Line Recording Object Beam Configurations

On-axis
Reference beam

Off-axis
Reference beam



(Pan,2003)

Advantages/Disadvantages of In-line

Advantages

- Greater Intensity Hologram
- Complex amplitude Particle Extraction
- Potential for particle size determination

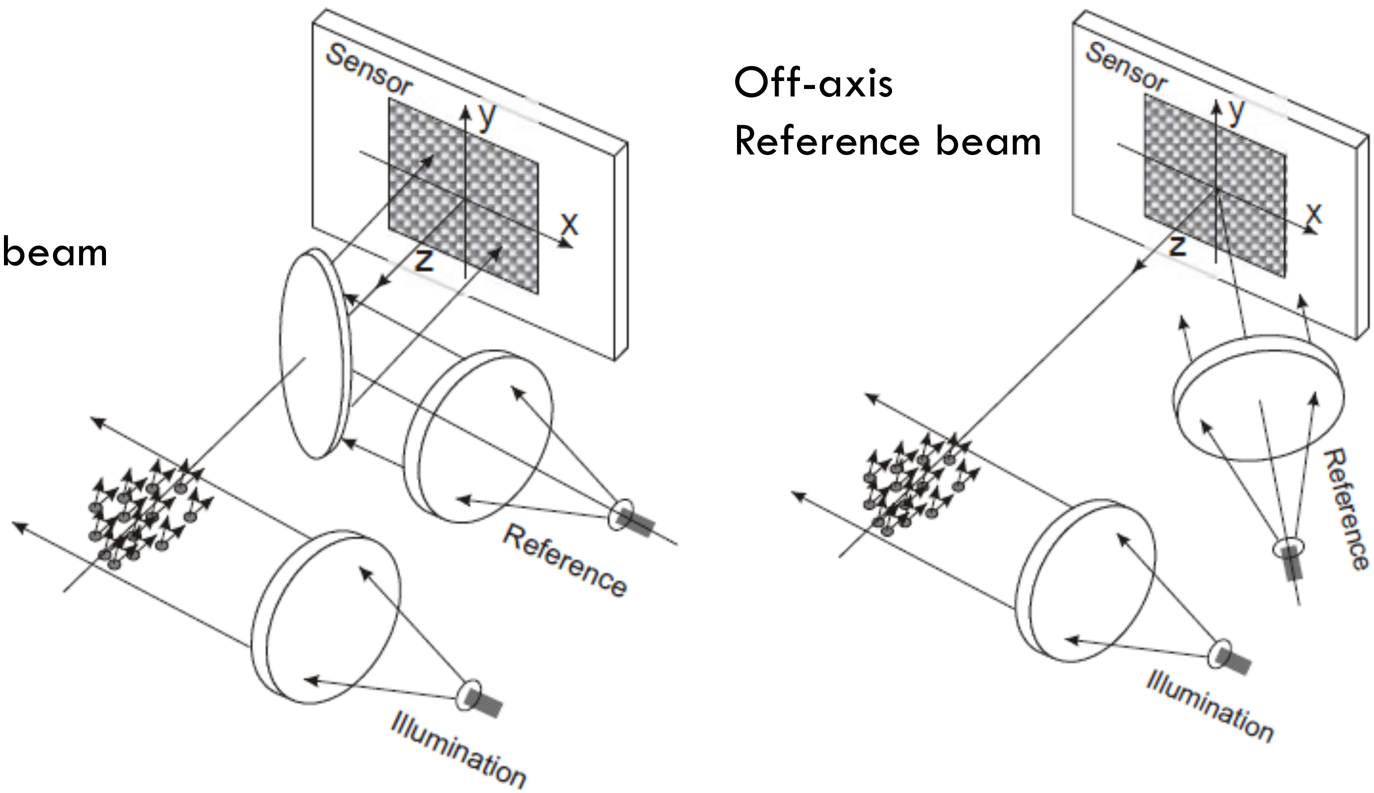
Disadvantages

- Excessive Speckle Noise from particles outside of region of interest resulting in large depth resolution errors
- Low Particle Seeding Density

Off-Axis Recording Object Beam Configurations

On-axis
Reference beam

Off-axis
Reference beam



Pan,2003

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Advantages/Disadvantages of Hybrid Holographic Recording

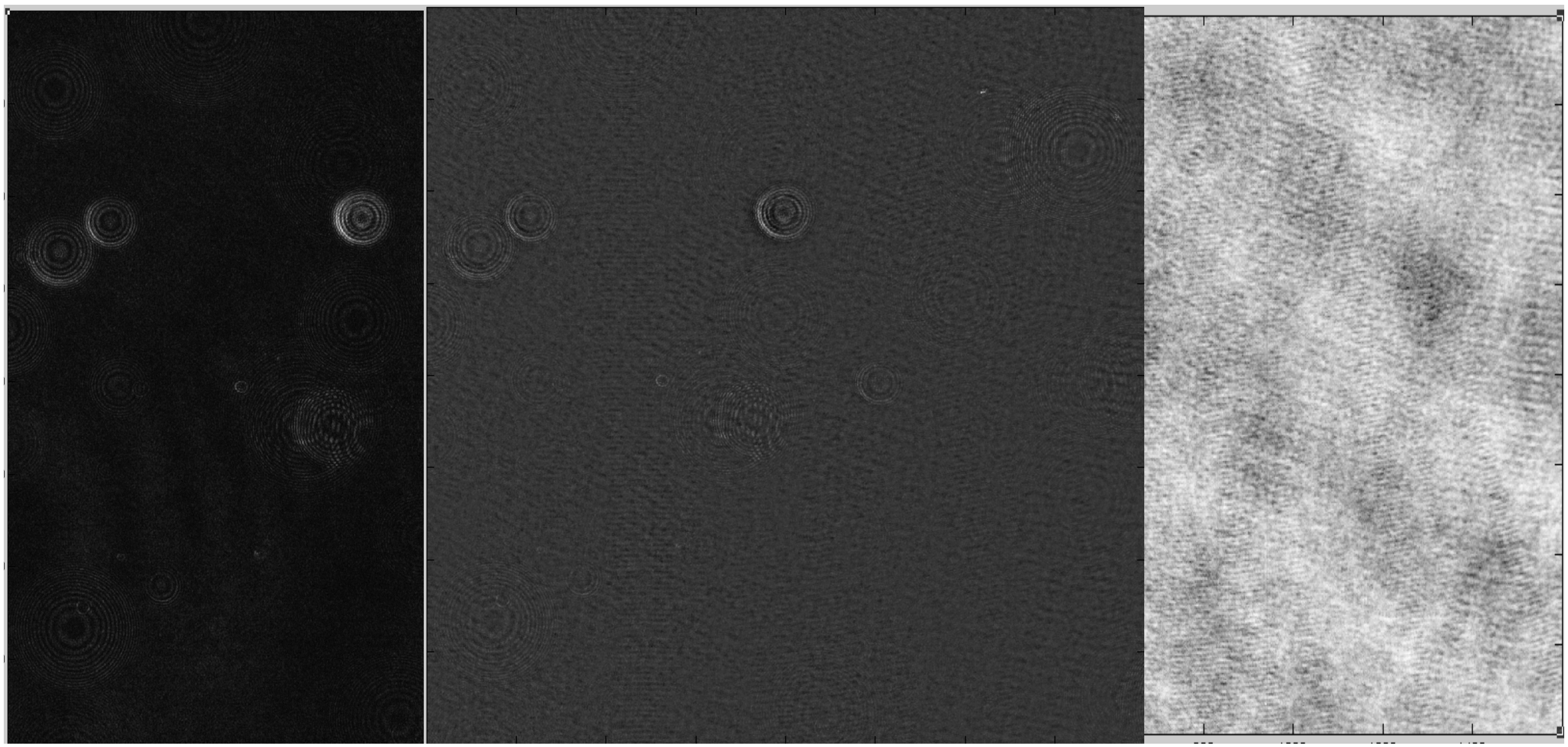
Advantages

- Speckle Noise suppression resulting from smaller imaged region
- Lower resolution requirement then off-axis reference wave configuration
- Facilities with higher particle concentrations can be imaged
- More accurate z location

Disadvantages

- No complex amplitude particle extraction methods

Subtraction with Background Image



Raw Hologram Image after Background Image

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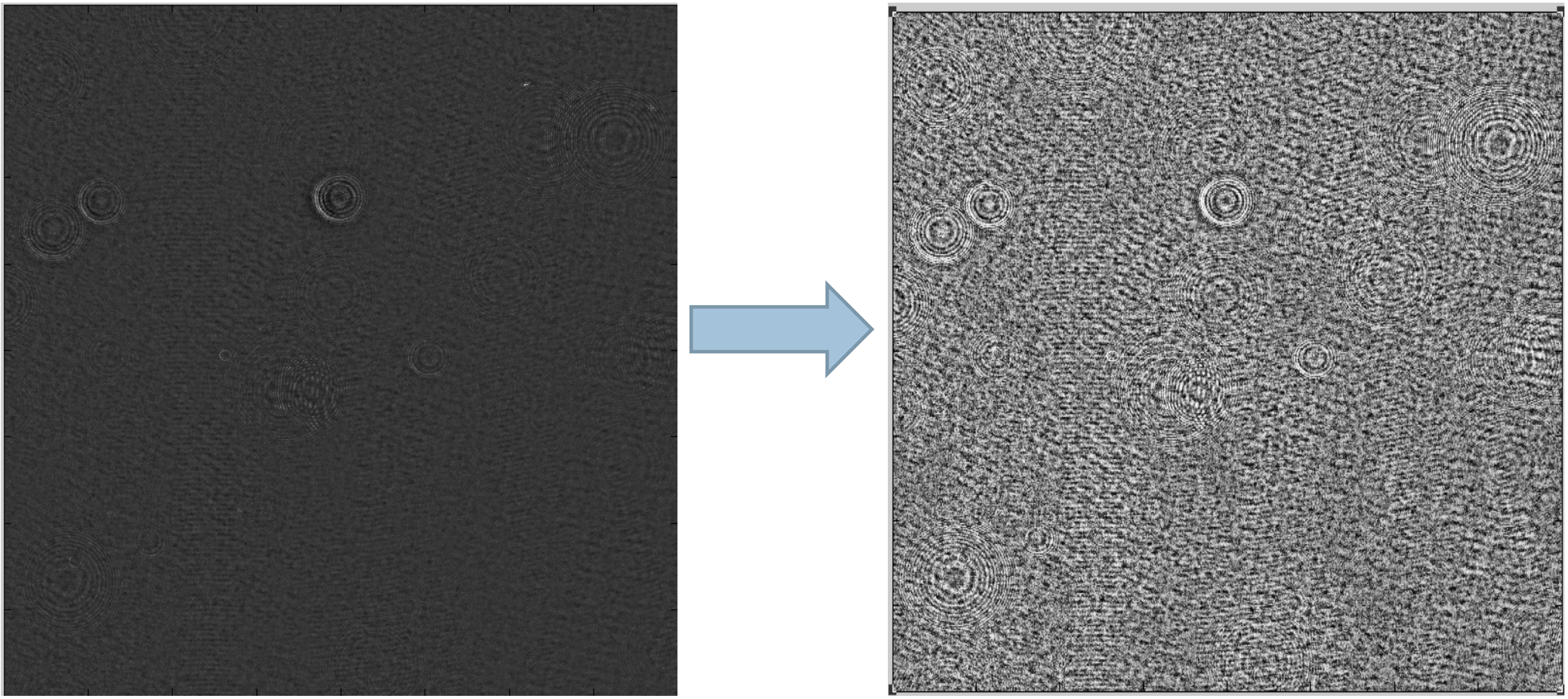
Contrast-limited adaptive histogram equalization and Imfilter



Holography with on-axis reference wave

$$I_H = |\mathbf{R}|^2 + |\mathbf{O}|^2 + 2|\mathbf{R}| \cdot |\mathbf{O}| \cdot \cos\left(\frac{\pi r^2}{\lambda z_0} + \varphi\right)$$

R= reference wave
O=object wave
Z= distance from focus plane
r = radial coordinate in the hologram recording system
λ = wavelength
φ = phase shift

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Numerical Reconstruction (Direct Method(Takaki,1999))

$$U(x,y,z)=\iint I_H(\xi,\eta)R(\xi,\eta)\frac{\exp(jk\rho)}{j\lambda\rho}d\xi d\eta$$

Fourier Transforms:

$$U(x,y,z)=\Im^{-1}\left\{\Im\left[I_H(\xi,\eta)\cdot R(\xi,\eta)\right]\cdot\Im\left[k_z(u,v)\right]\right\}$$

Diffraction kernel

$$k_z(x,y,z)=\frac{1}{j\lambda}\cdot\frac{\exp(jk\sqrt{x^2+y^2+z^2})}{\sqrt{x^2+y^2+z^2}}$$

Discrete Form

$$K_z(m,n)=\exp\left[-j\frac{2\pi z}{\lambda}\sqrt{1-\left(\frac{\lambda m}{N_x\Delta_x}\right)^2-\left(\frac{\lambda n}{N_y\Delta_y}\right)^2}\right]$$

Fourier Transform of:

$$K_z(u,v)=\exp[jkz\sqrt{1-(\lambda u)^2-(\lambda v)^2}]$$

m,n= matrix indices

N_x,N_y= *number of pixels*

Δ_x , Δ_y = pixel size in x an y directions

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Particle Extraction

Particle Extraction using Intensity(PEI)

- Only available method for side scattering due to irregular distribution of scattered wave in side scattering

The intensity based centroid of the particle (x_p,y_p,z_p) is calculated from the relationships,

$$x_p = m_{100}/m_{000}, y_p = m_{010}/m_{000}, z_p = m_{001}/m_{000}$$

where a moment of order ($p+q+r$) of the intensity I is given by,

$$m_{pqr} = \sum_{-\infty}^{\infty}\sum_{-\infty}^{\infty}\sum_{-\infty}^{\infty} i^p j^q k^r I(i,j,k)$$

(DeJong,2008)

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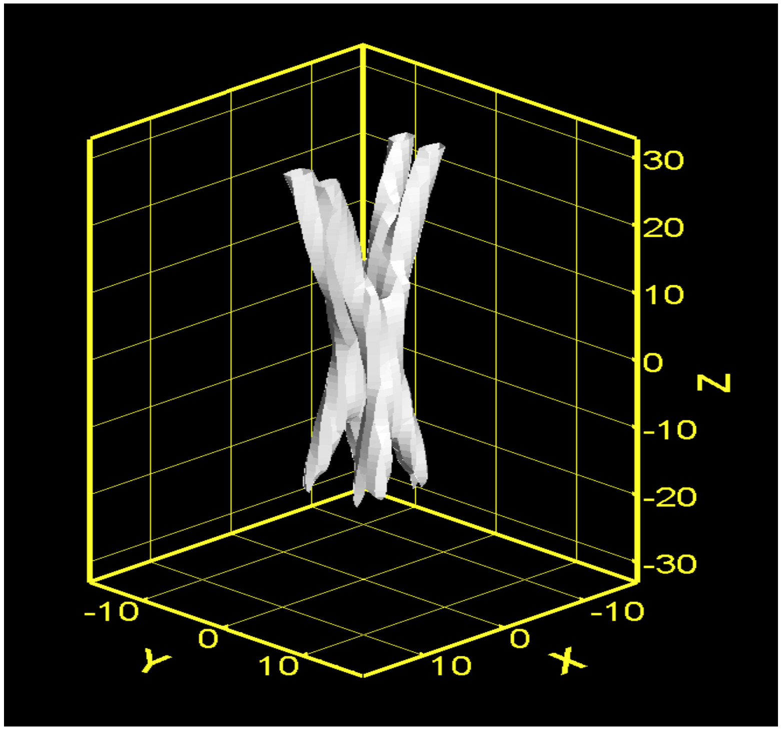
Problems with particle centroid calculation



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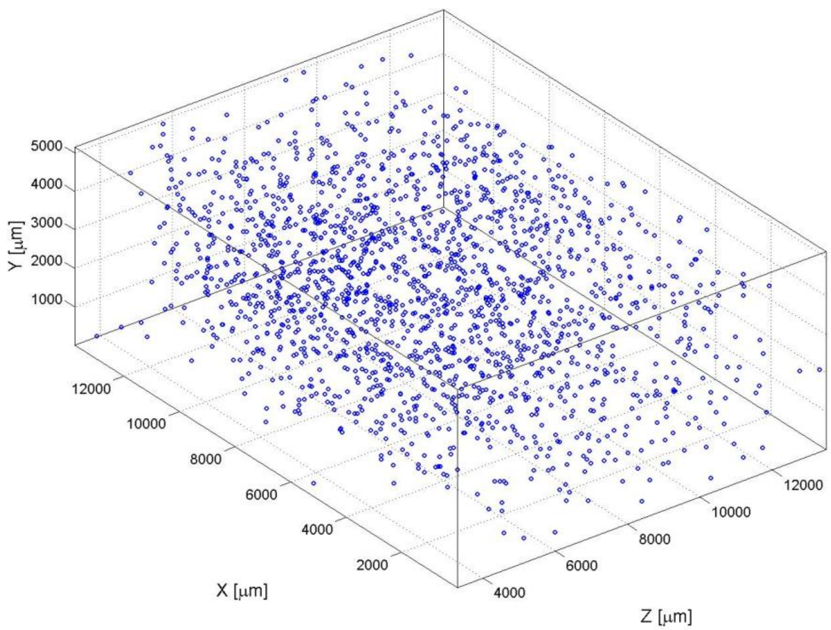
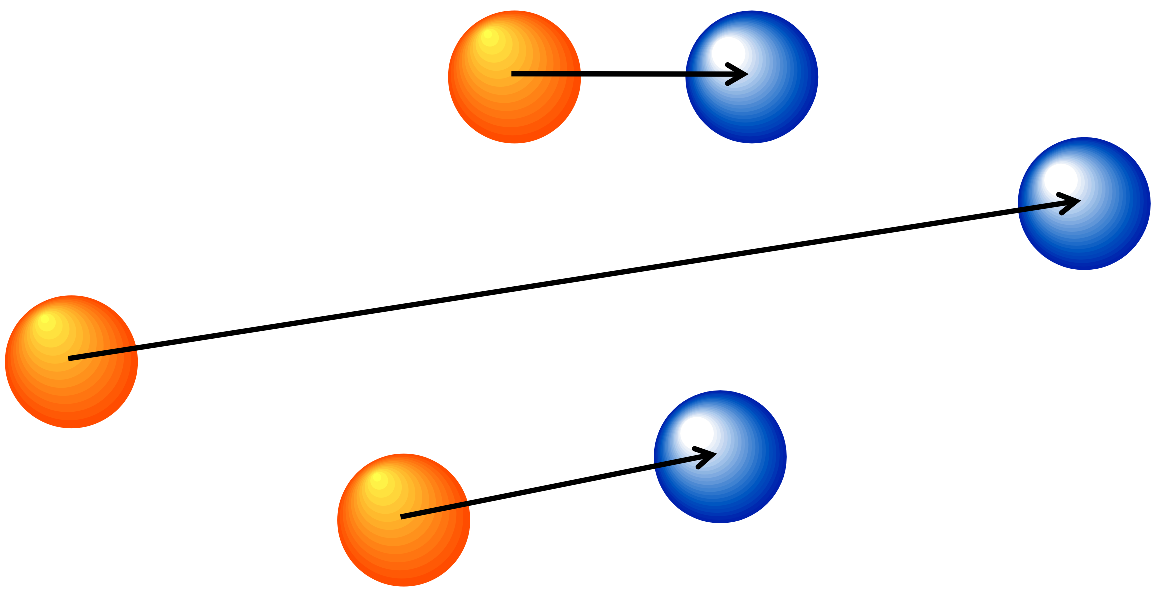
3D Reconstructed Particle Field



(DeJong,2008)

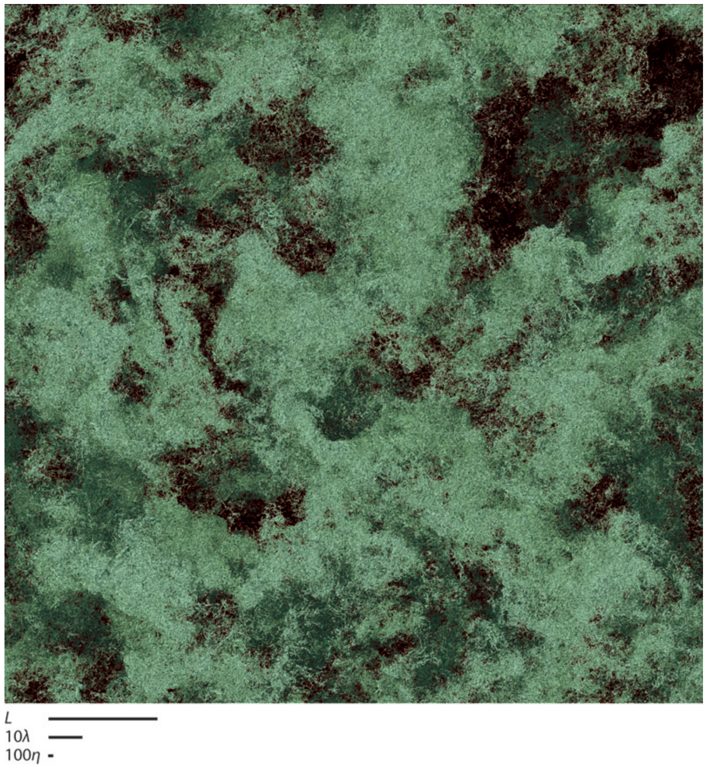
Velocity Extraction

Nearest Neighbor(Ouellette,2006)



What is Turbulence ?

- Rotational and Dissipative
- Non-linear
- Stochastic(random)
- diffusive



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Isotropic Turbulence

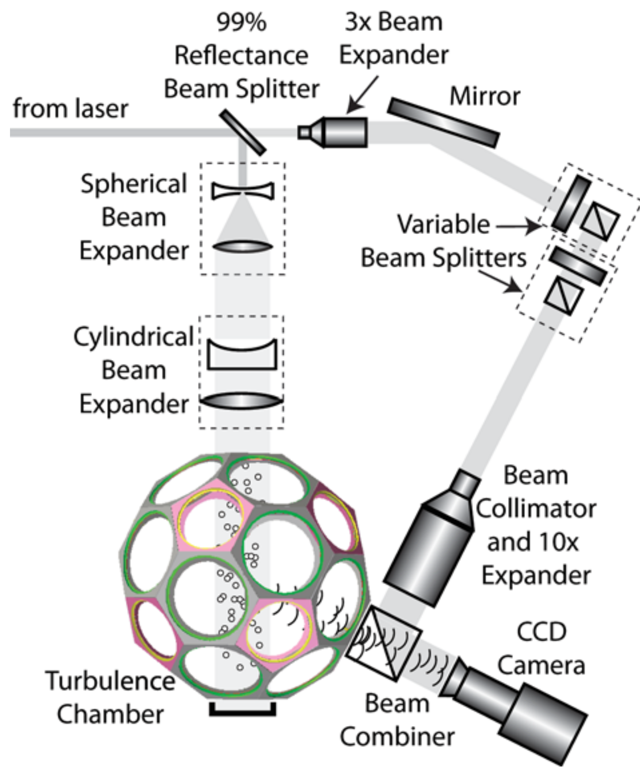
Singlepoint Velocity Correlations

$$\langle u^2 \rangle = \langle v^2 \rangle = \langle w^2 \rangle$$

$$\langle uv \rangle = \langle vw \rangle = \langle wu \rangle = 0$$

Homogeneous Turbulence in which all the fluctuation statistics have no preferred directionality. All statistics are independent of coordinate rotations and reflections

My Research



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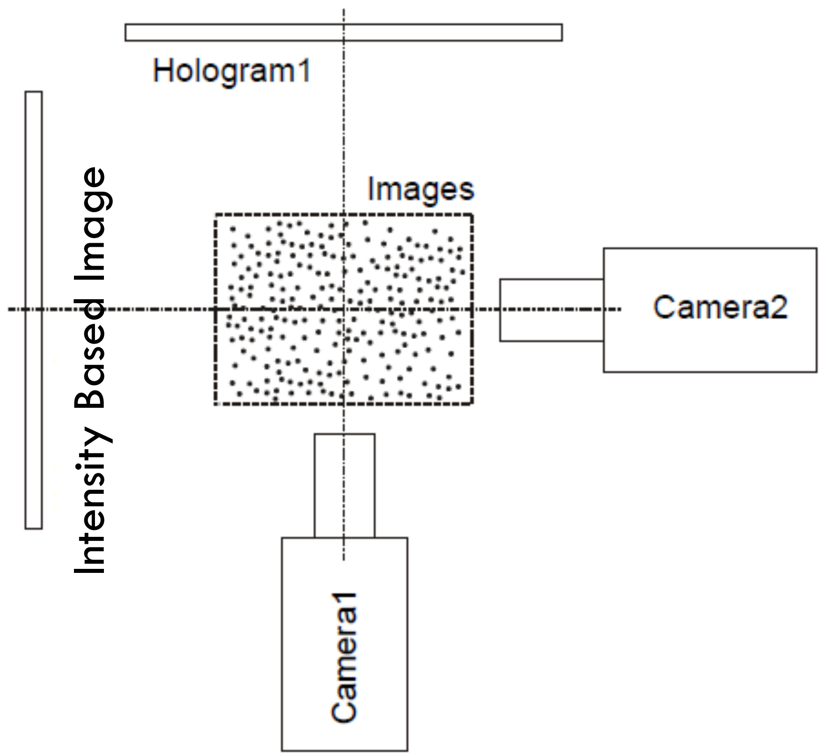
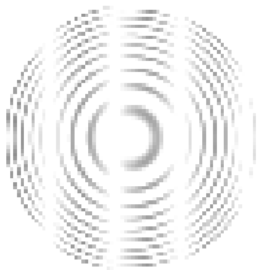
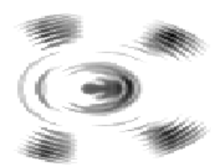
For my experiment
(first assume perfectly orthogonal setup has been completed)



Simulation of Holographic Particle (completed)

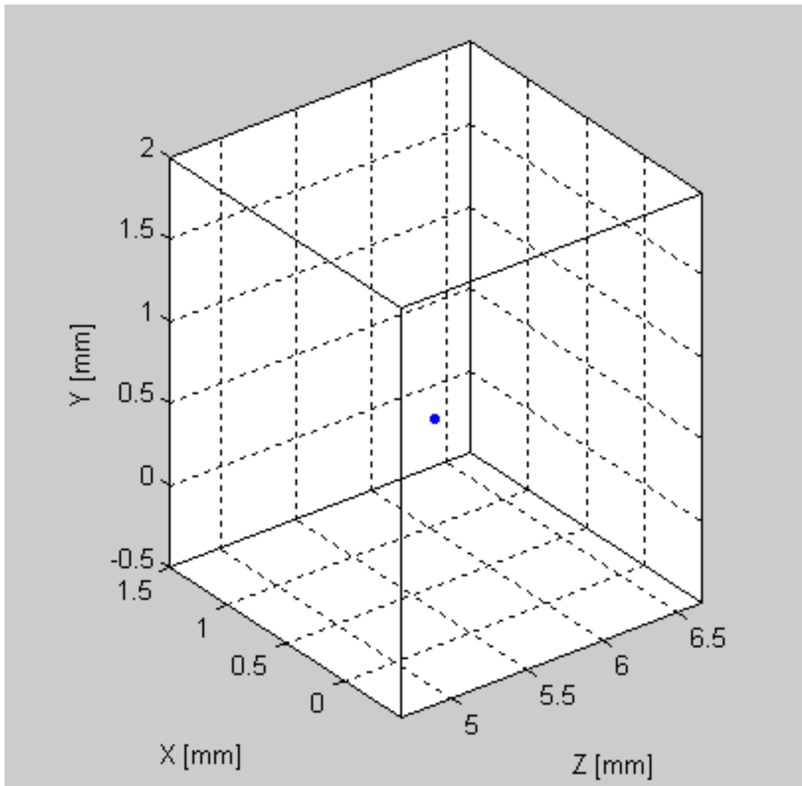


Synthesized Hologram



Hologram after Gaussian Blurr

Correspondence of Reconstructed Hologram with Intensity Based Image (currently working on)



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Other Minimum goals to be completed

- Determination of Particle Size via pixel count
- Simulate Movement of particles for a given Time Step

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Long Term Goals

- Multiple Particle Image Correspondence
- Multiple Particle Velocity Extraction
- Particle matching for a non-uniform particle field

References

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