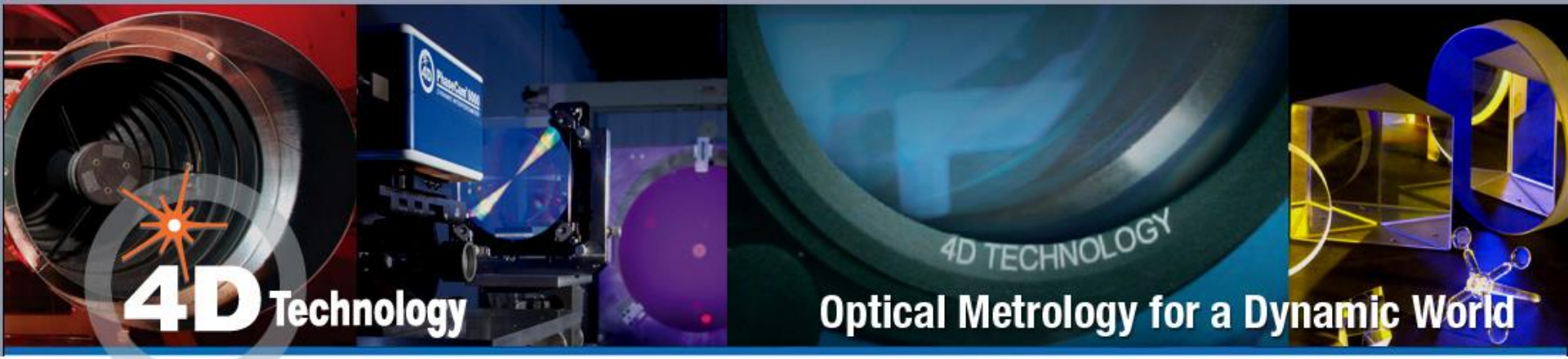
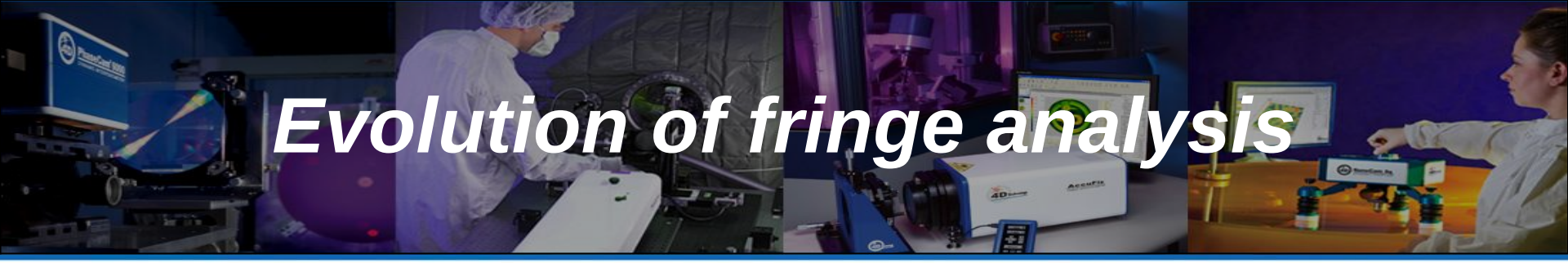
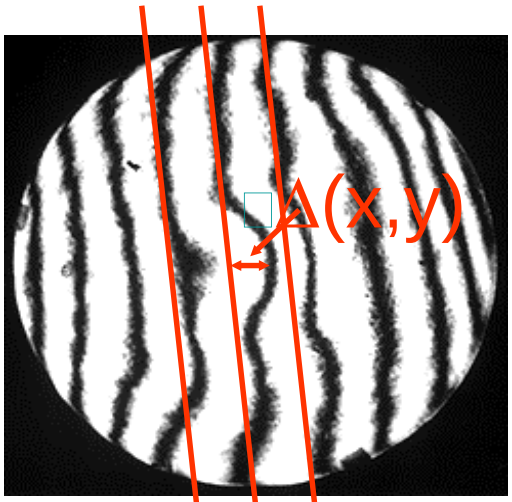



# *Polarization Structured Light For Handheld 3D Surface Measurements*



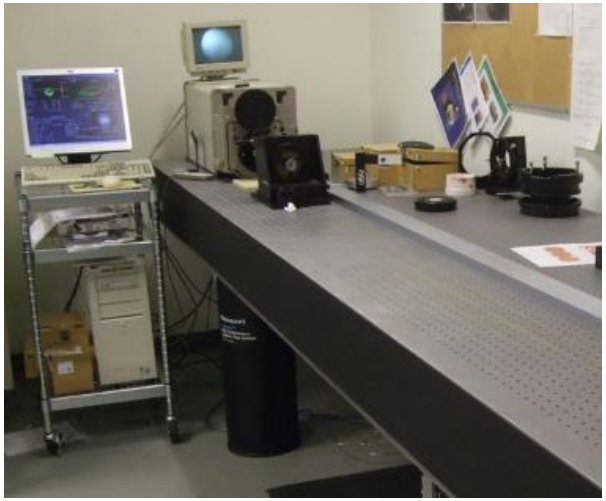
# Evolution of fringe analysis

- By Hand




λ/10

- Temporal PSI
  - Precision



<λ/1000

- Dynamic PSI
  - Portable

<λ/10,000

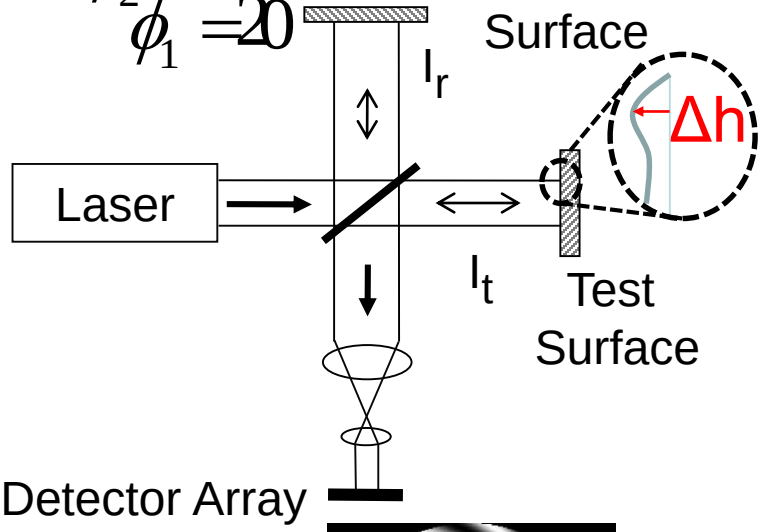
# Temporal Phase-Shift Interferometry

$\phi_4 = \frac{3\pi}{2}$

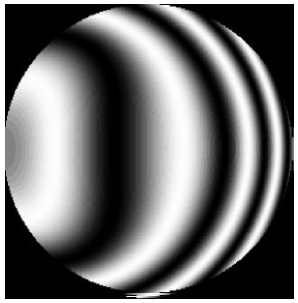
$\phi_3 = \pi$

$\phi_2 = \frac{\pi}{2}$

$\phi_1 = 0$



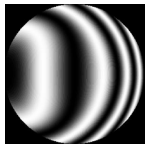

$I_2(x,y)$



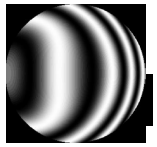
$I_n = I_T(1+\gamma COS(\phi + \phi_n)$

$\phi = 4\pi\ \Delta h/\lambda$

$\gamma = 2\ \sqrt{(It \bullet Ir)/(It+Ir)}$



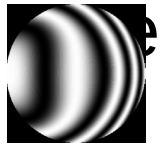
$I_1 = I_T(1+\gamma Cos(\phi))$



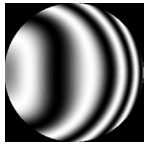
$I_2 = I_T(1+\gamma Sin(\phi))$

Is it a hill or valley?

eflectivity or surface?



$I_3 = I_T(1-\gamma Cos(\phi))$



$I_4 = I_T(1+\gamma Sin(\phi))$

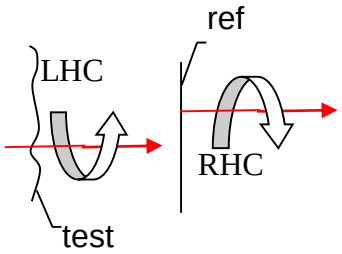
**120 milliseconds for acquisition**

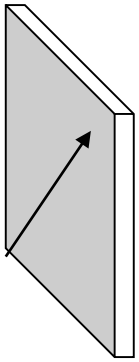
$$Tan(\phi(x,y)) = \frac{I_4(x,y) - I_2(x,y)}{I_3(x,y) - I_1(x,y)}$$

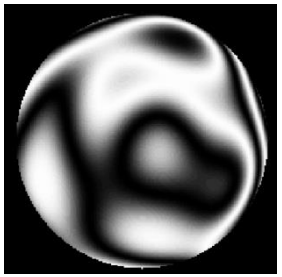
$$Height(x,y) = \frac{\lambda}{4\pi}\phi(x,y)$$

# Polarization Phase Shift Method

## Use polarizer as phase shifter



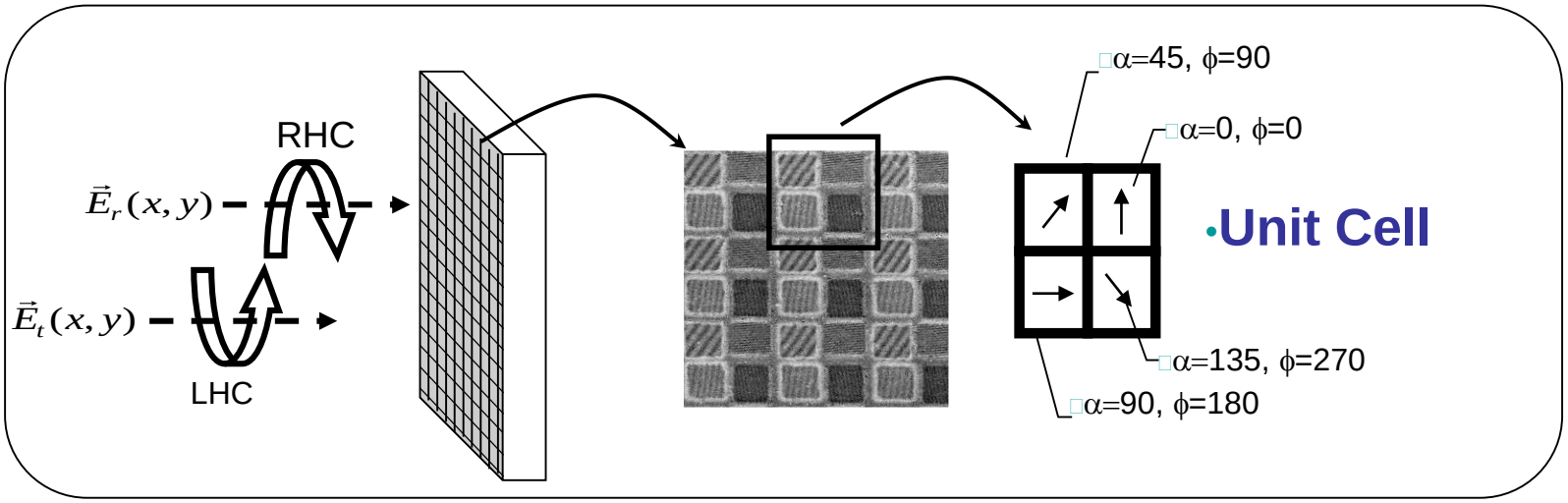


**Circular polarized beams (θ) + linear polarizer (α)** ⟹ $I = I_T(1+\gamma Cos\,(\theta + 2\alpha))$

**Phase-shift depends on polarizer angle**

**Kothiyal and Delsile, (1985)**

# Simultaneous polarization phase-shift – micro-polarizer camera



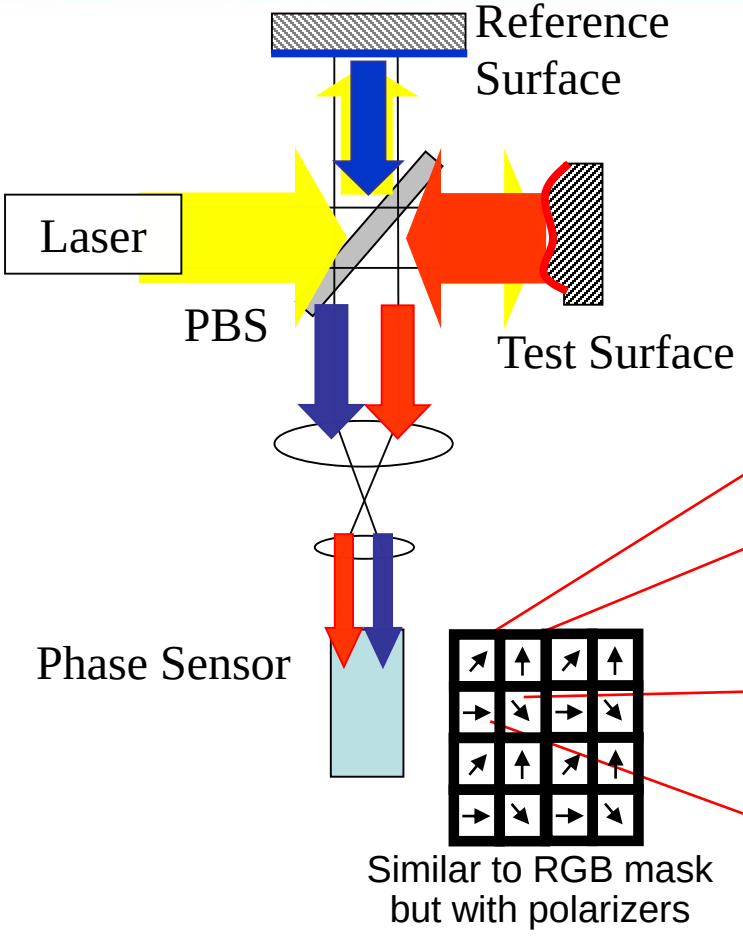

- Array of oriented micropolarizers
- Similar to RGB color mask
- On-axis imaging, broadband wavelength

- **Dynamic Interferometry™**

  **"Precision measurement in dynamic environments"**

US Patent 7,230,719 (2004)

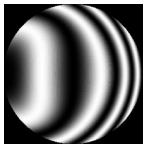
# Dynamic Interferometry



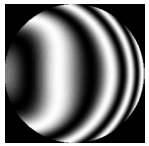

Use polarization to code the beams

**Red = p**

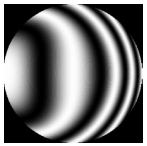
**Blue = s**



$$I_1(x,y) = 1 + Cos[\theta(x,y)]$$



$$I_2(x,y) = 1 - Sin[\theta(x,y)]$$

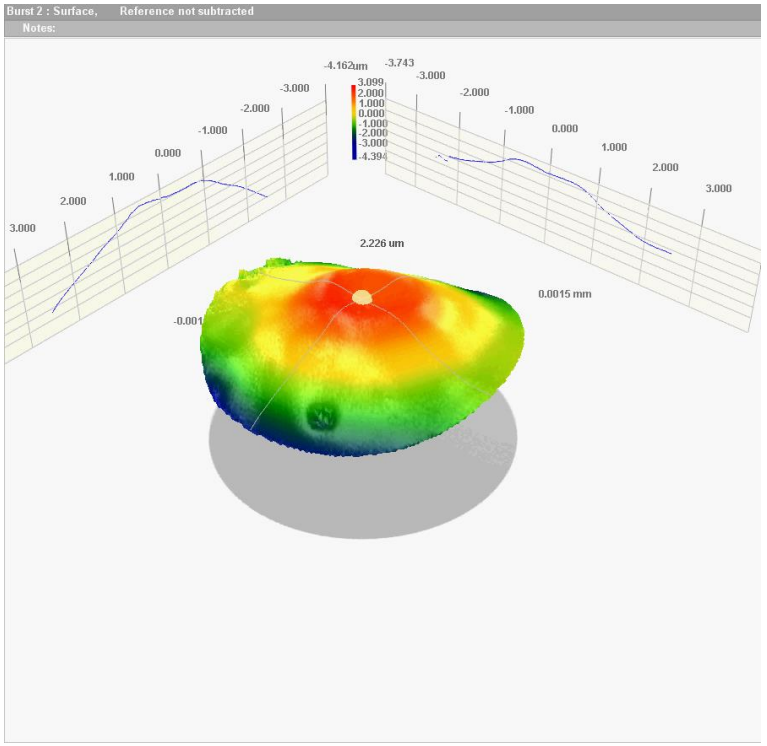


$$I_3(x,y) = 1 - Cos[\theta(x,y)]$$

$$I_4(x,y) = 1 + Sin[\theta(x,y)]$$

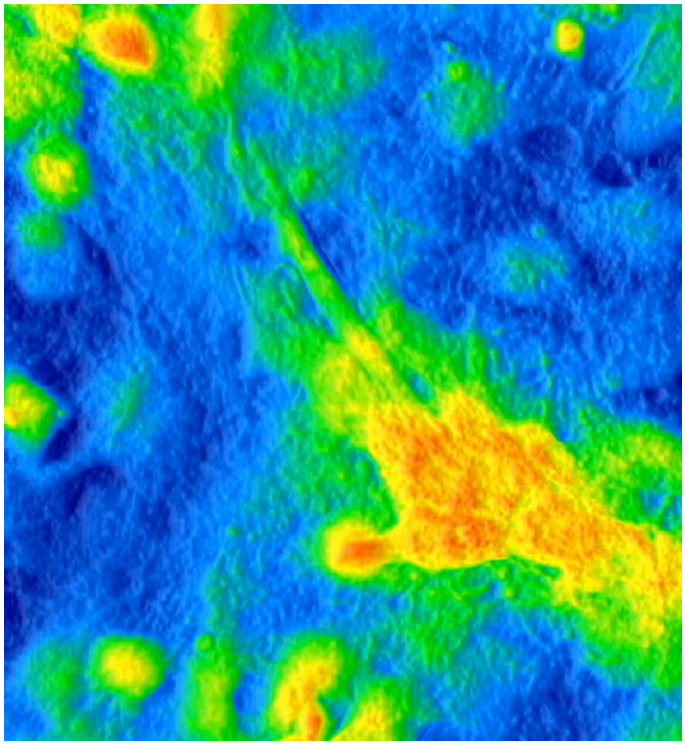
**Nanoseconds for acquisition!**

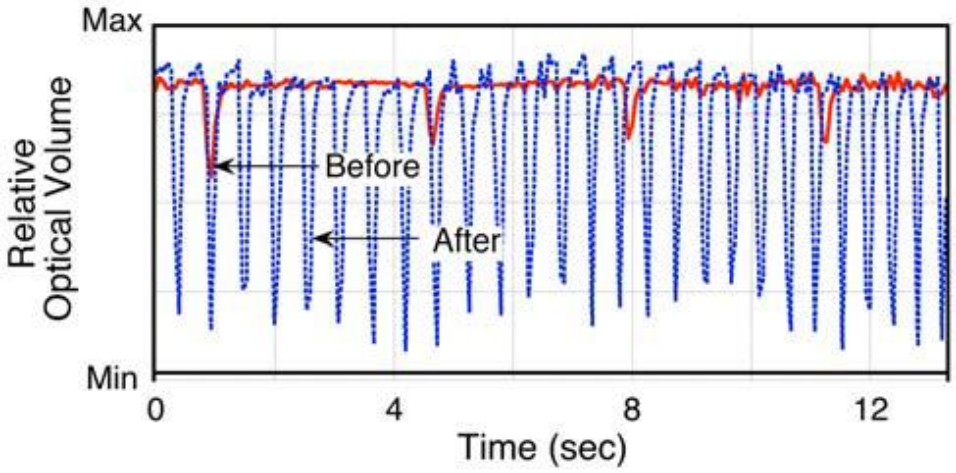
# Dynamic Measurement of Human Eye



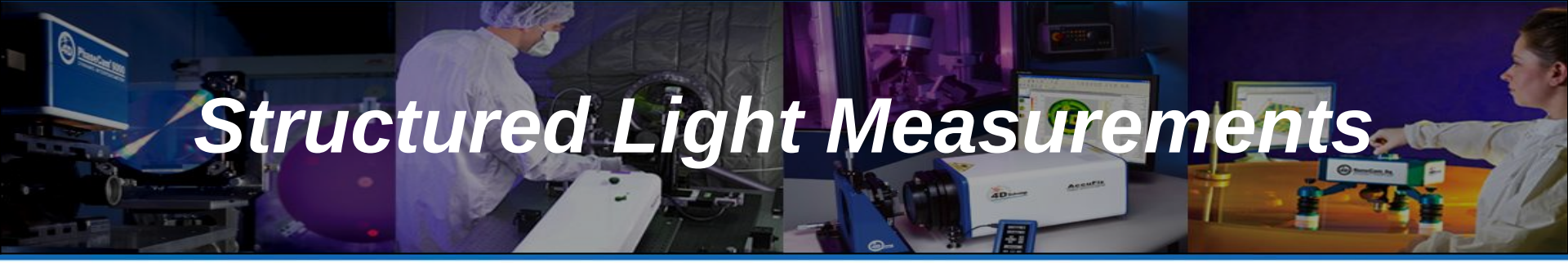
# Dynamic Phase Imaging

- Rat cardiac myocytes – before & after administering drug



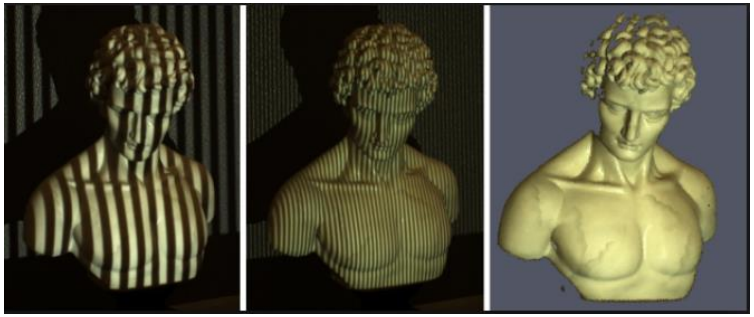


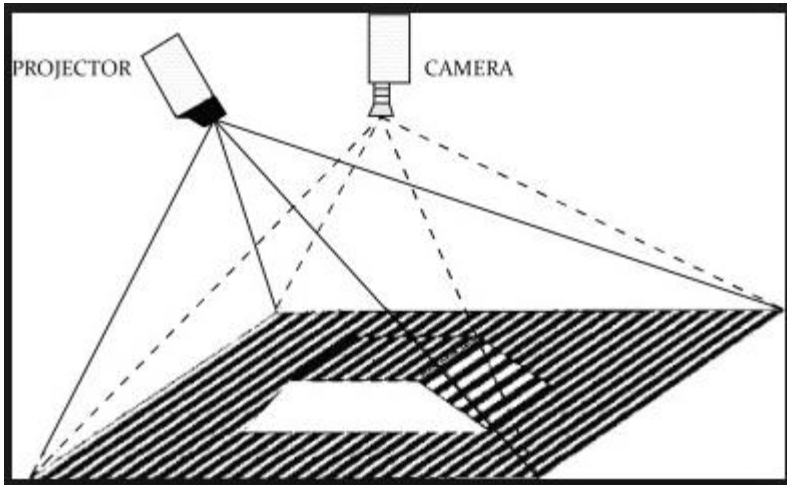

- Both frequency and strength are measured



# Structured Light Measurements

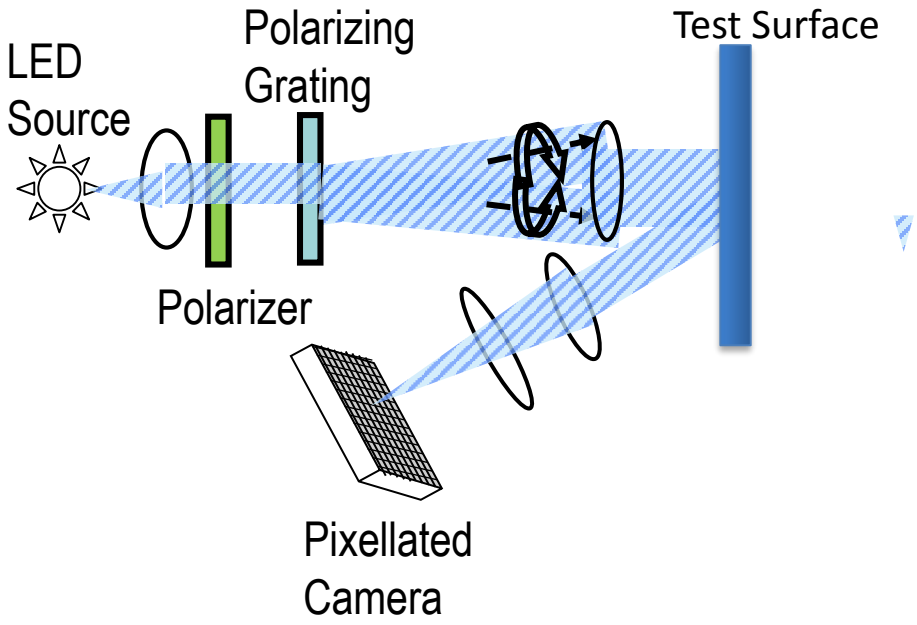
- Project stripes onto a surface.
- Use deformation of stripes to determine surface shape
- To determine high vs. low points, take multiple images, changing frequency, color, or angle.
- Not suited for vibration-rich environments





# Polarization Structured Light (PSL) Combines Dynamic Interferometry with Fringe Projection

- Use specialized grating to create two orthogonally polarized beams
- Create ‘virtual’ fringes on test part (cannot see with naked eye)
- Use 4D’s pixelated camera to view fringes and determine surface shape



# Sections of the InSpec