Medical Robotics
Lecture 21
Computer Vision II:
Color Spaces, Robot Calibration, and 3D Imaging
Nov 8th

Axel Krieger, PhD
Assistant Professor

Department of Mechanical Engineering, University of Maryland, College Park, MD, USA

axel@umd.edu

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Outline

- Segmenting images using color
- Robot-Sensor Calibration
- Depth Sensing

- Sources: Simon Leonard (JHU)

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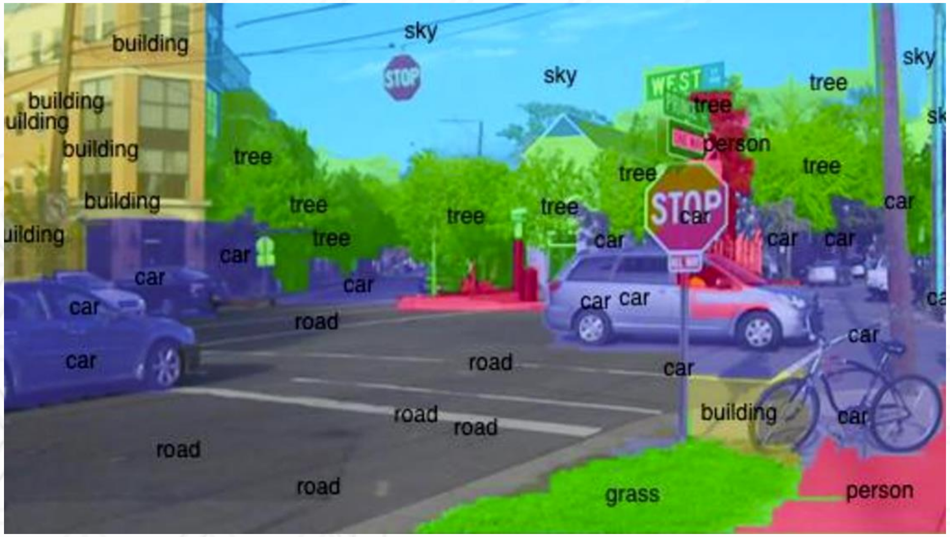
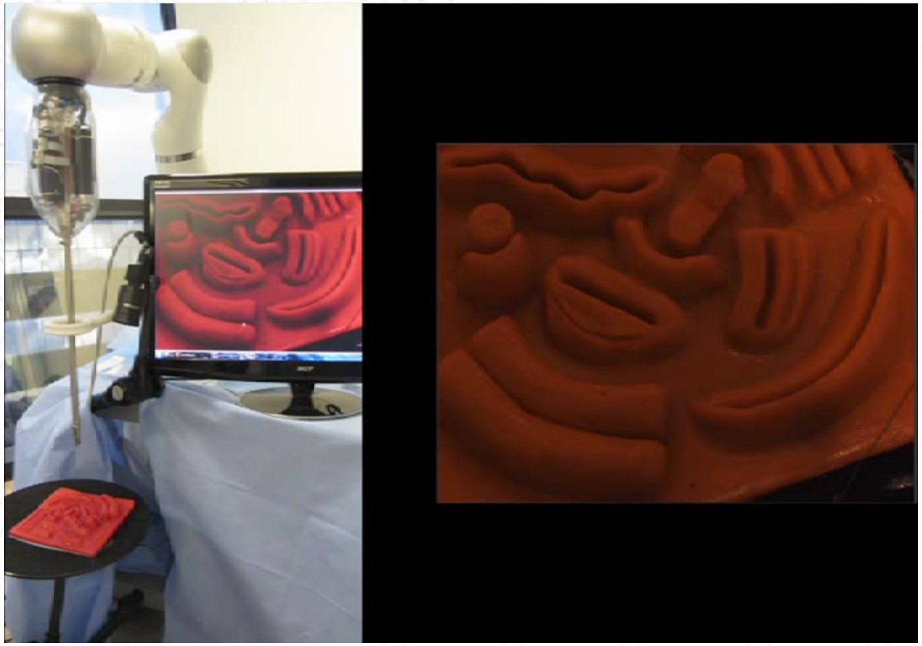
Motivation for Segmentation using Color Spaces

- Goal: Detect objects in images
- Method: Use color differences





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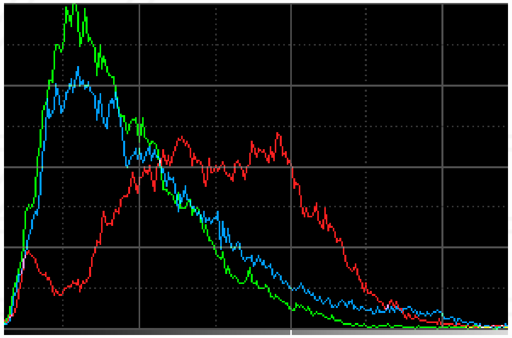
Color Spaces

- Utilize color to segment images
  - First try: Segment image according to the color histogram. Find clusters in the RGB space.
  - Problem: In the RGB space, lightening, texture, and shadows alter the RGB values.



Example RGB histogram

Image to segment

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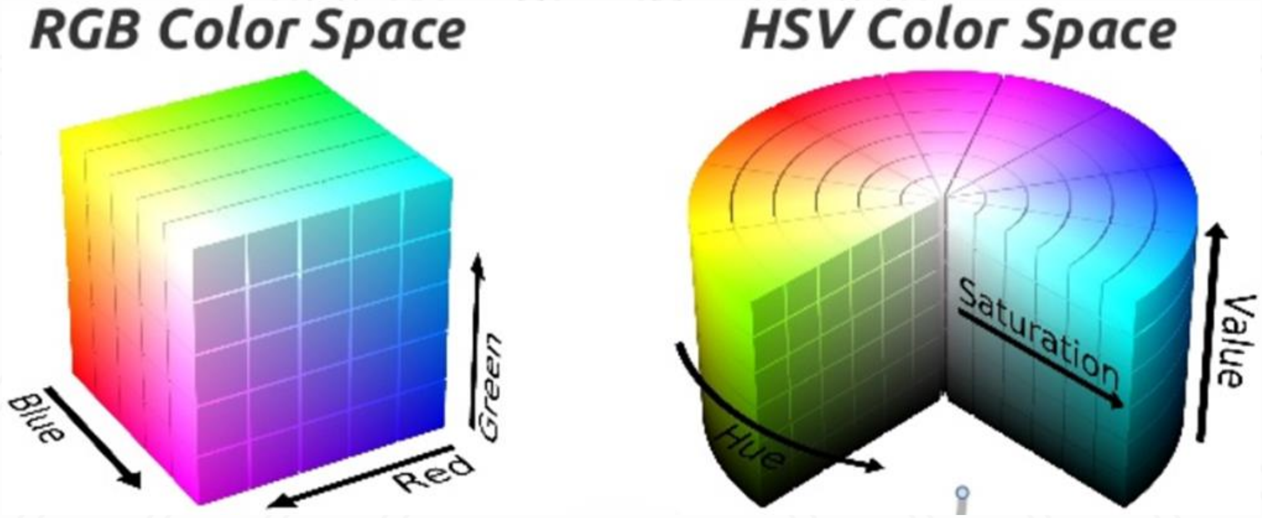
Color Spaces

- Utilize color to segment images
  - Solution: Convert the RGB image to another image space containing an intensity component – omit this component from segmentation.
  - Example: HSV, Lab



Color Spaces

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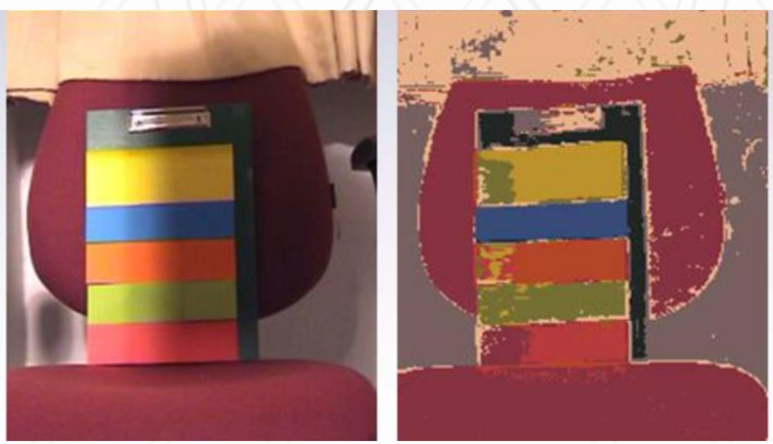
  - Solution: Convert the RGB image to another image space containing and intensity component – omit this component from segmentation.
  - Example: HSV, LAB

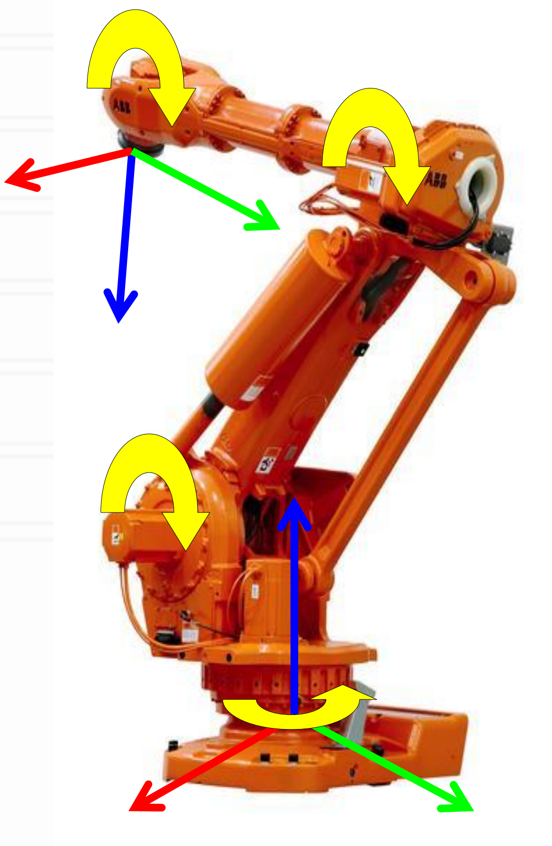
Original image



Color segmentation using the HSV model

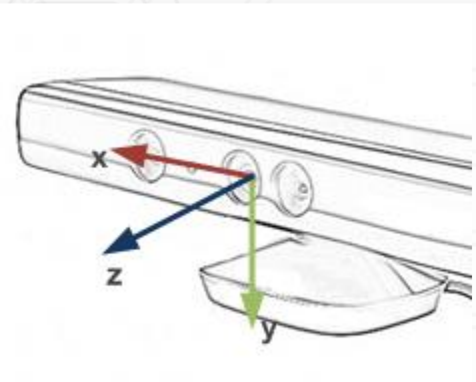
Robot Calibration: Coordinate Frames

On robots



6 axes robot arm

On sensors



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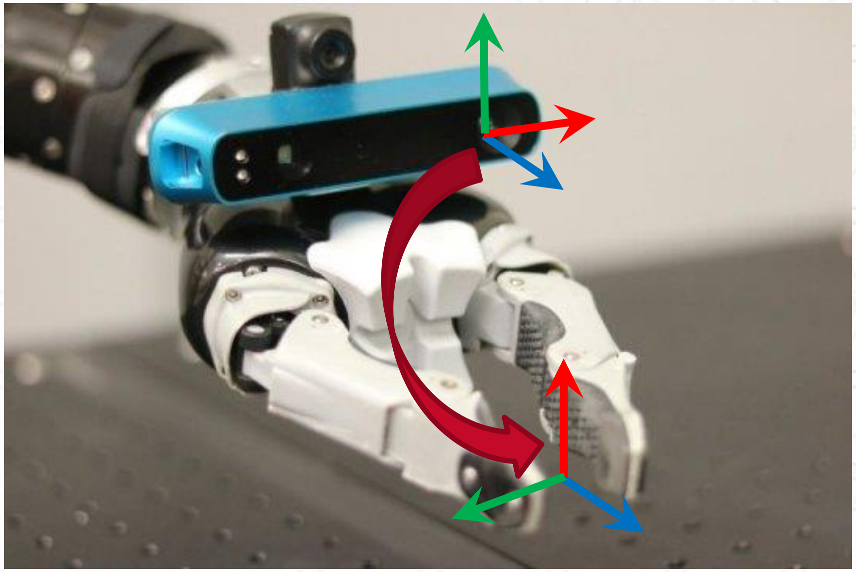
Combining Sensors and Robots

“Eye-in-Hand”



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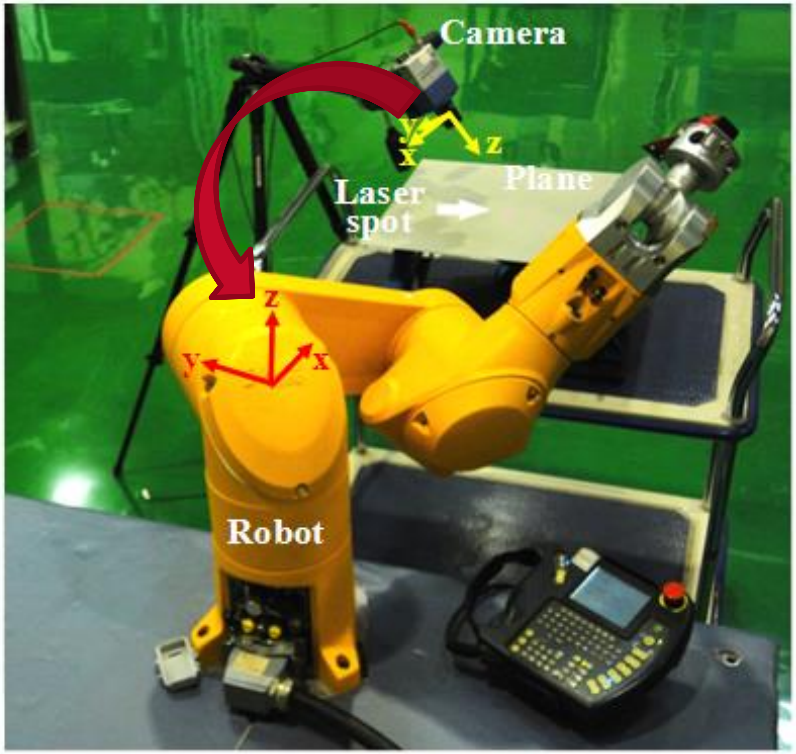
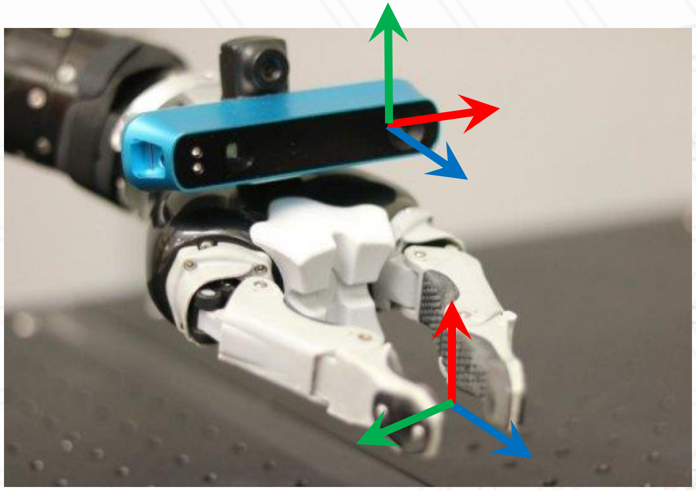
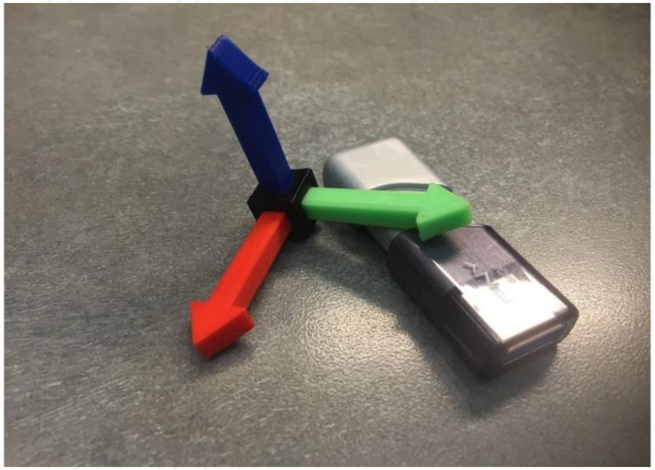
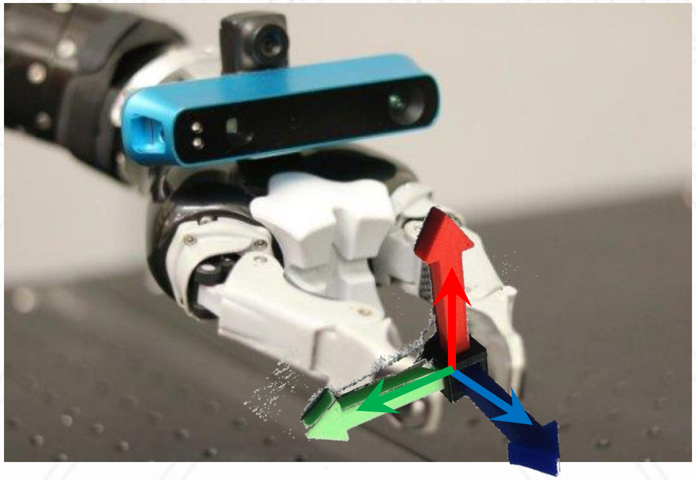
“Eye-to-Hand”



Why Hand-Eye Calibration?







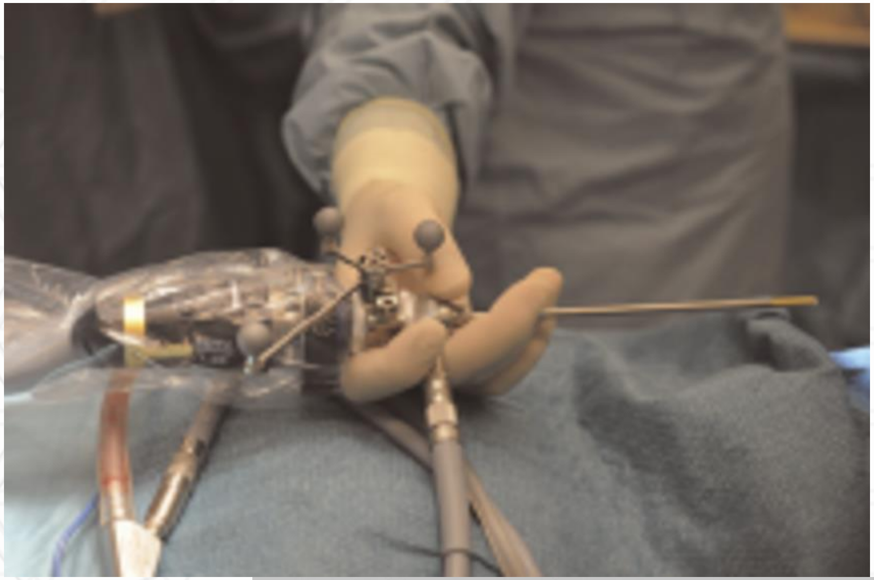
Hand-Eye Calibration

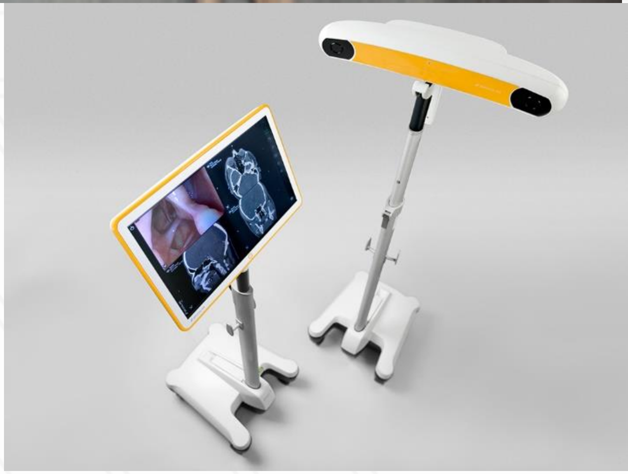
- Find the transformation between the coordinate frame of the sensor and a coordinate frame on the robot.
- This transformation “X” must be known if measurements from the sensor are used to control the motion of the robot.

Not Just for Robots

Use for any sensor that is tracked by some device

- Navigation system tracks an endoscope in 3D and can "register" the position of the device to the patient's CT
- Endoscope images are in the camera coordinate frame
- Hand-eye calibration will relate the images of the endoscope to the patient's CT





Robot Calibration

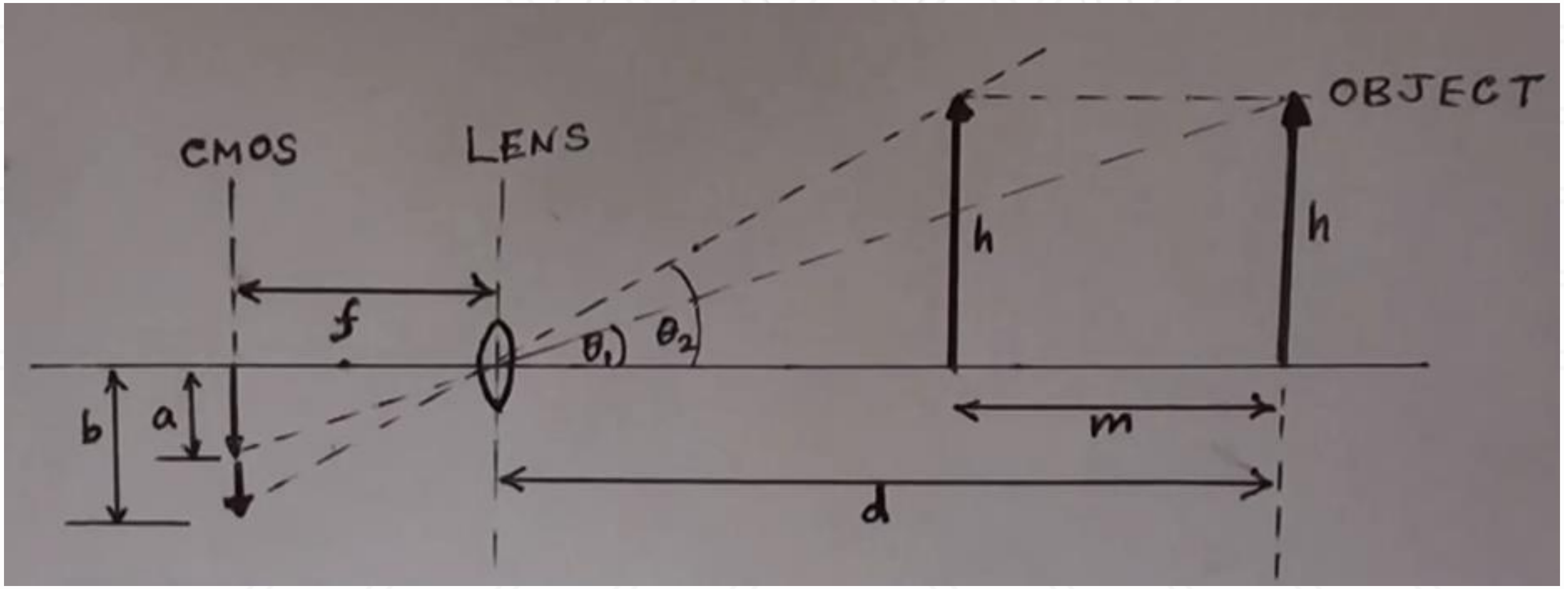
- Method for eye-to-hand calibration written on board…

Robot Calibration: Practical Considerations

- Method depends on accurate FW Kinematics, e.g. straight needle, correct parameters such as link lengths.
- Don’t move camera with respect to robot after calibration
- In practice, one often uses offsets to adjust for calibration errors
  - Move robot to a target and measure error
  - Include offsets to reduce error
- For increased accuracy, one can repeat calibrations at several checkerboard poses and use regression algorithm to compute transformation.

Depth with single camera

1. Depth measurement of object with known size
2. Depth measurement by moving camera (or object)



Depth with single camera

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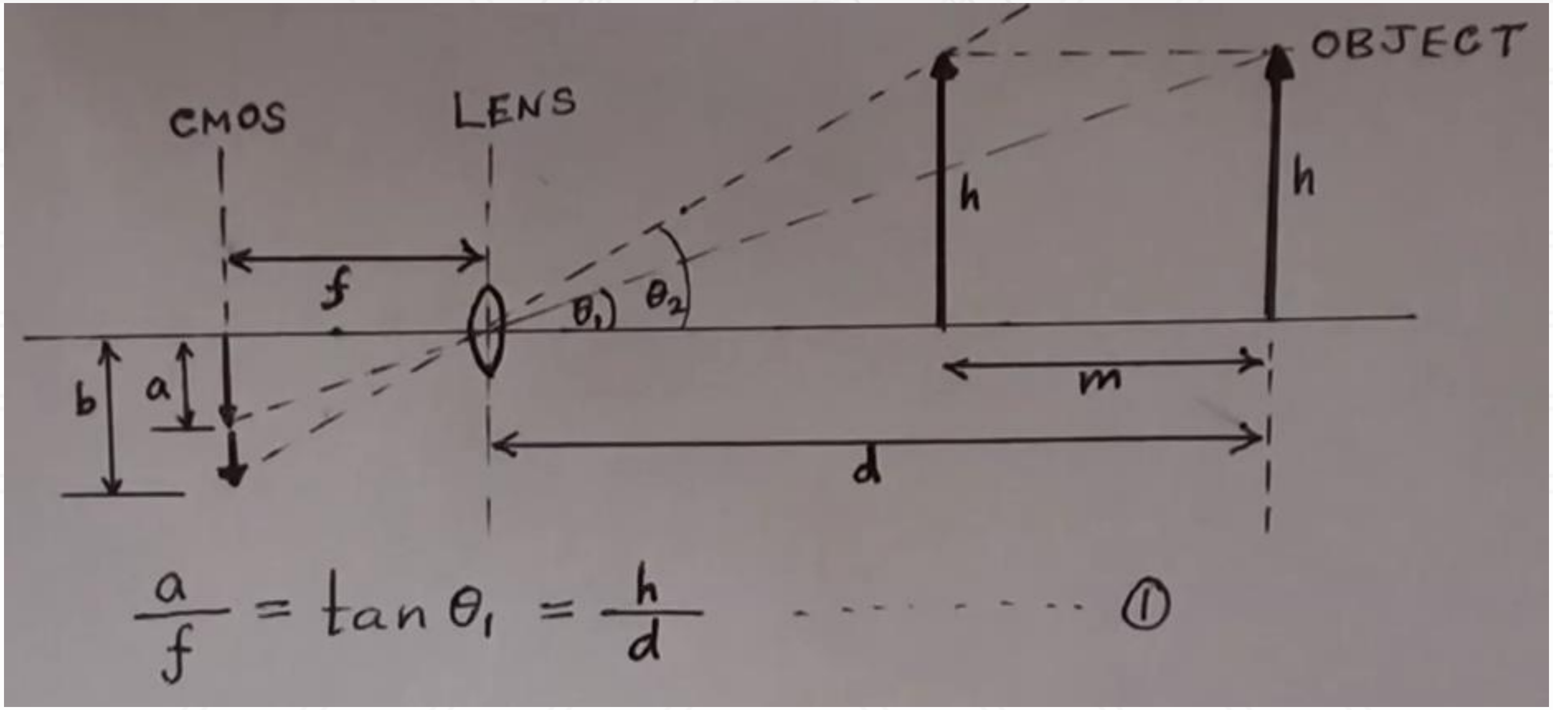
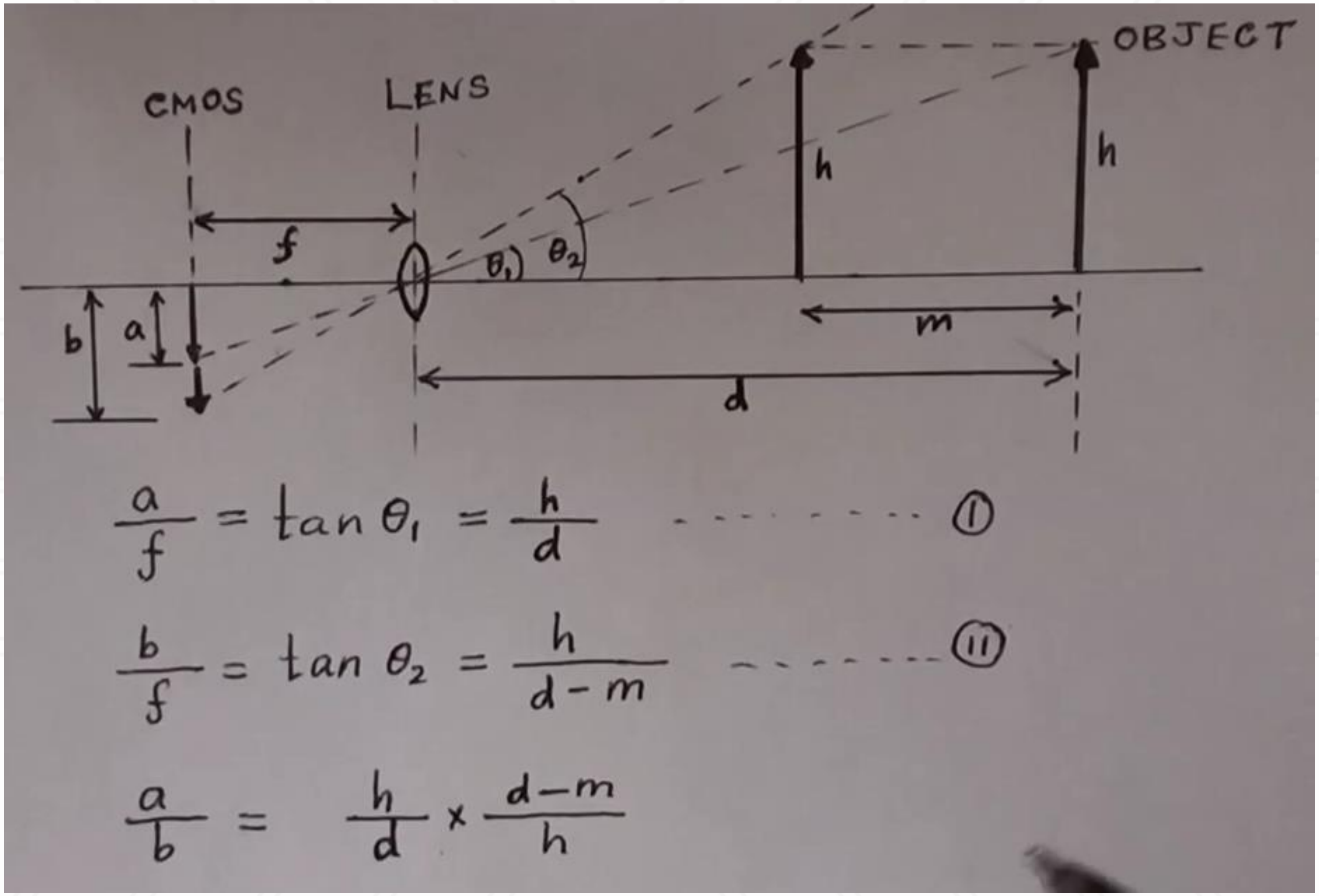


$d = h \cdot f/a$

Depth with single camera

2. Depth measurement by moving camera (or object)



Depth with single camera

2. Depth measurement by moving camera (or object)

$$\frac{a}{f} = \tan\theta_1 = \frac{h}{d} \quad \text{.........} \quad (\mathrm{I})$$

$$\frac{b}{f} = \tan\theta_2 = \frac{h}{d-m} \quad \text{.........} \quad (\mathrm{II})$$

$$\frac{a}{b} = \frac{h}{d} \times \frac{d-m}{h}$$

$$\frac{a}{b} = \frac{d-m}{d} = 1 - \frac{m}{d}$$

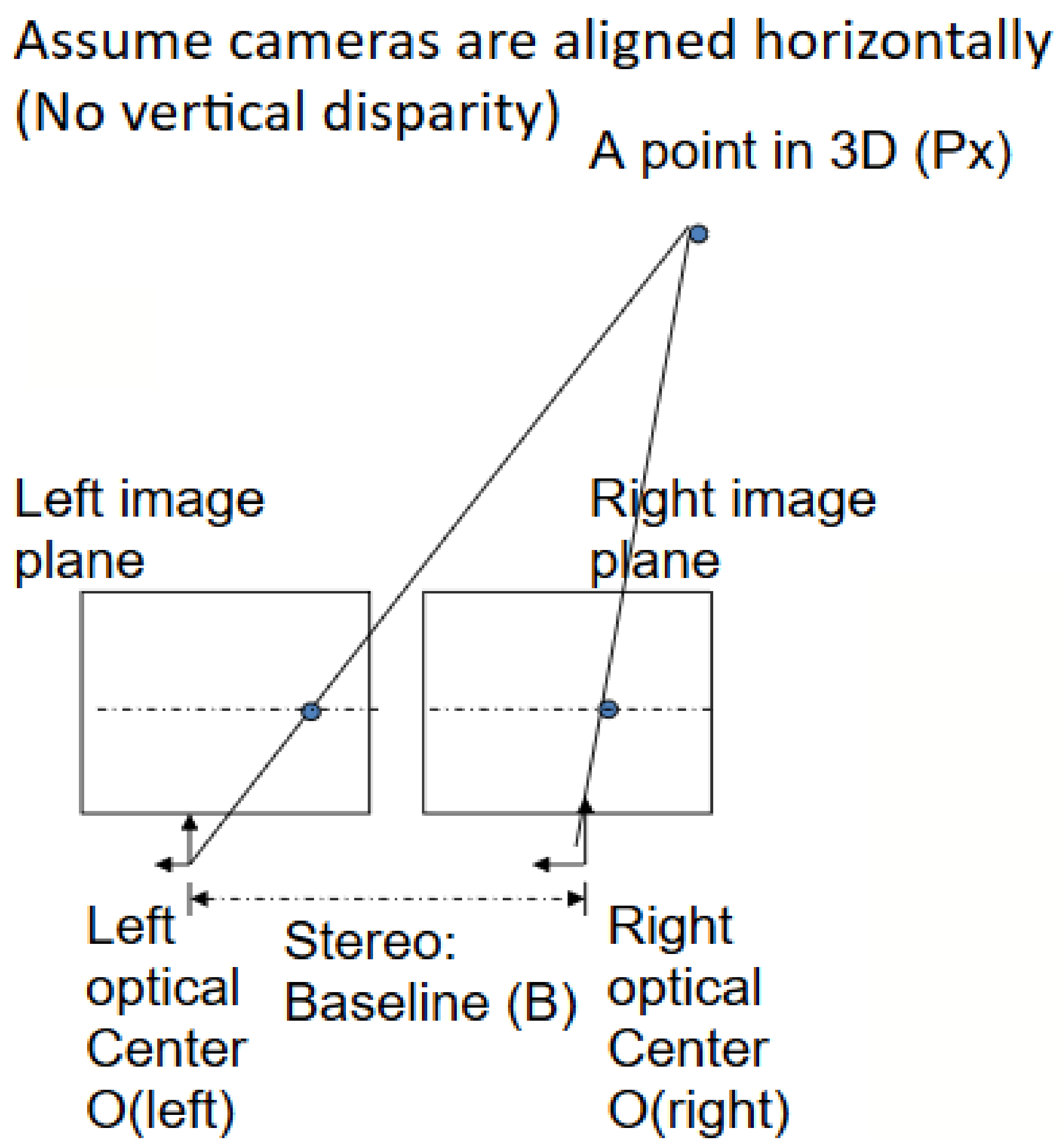
$$\frac{m}{d} = 1 - \frac{a}{b}$$

$$d = \frac{m}{1-\frac{a}{b}}$$

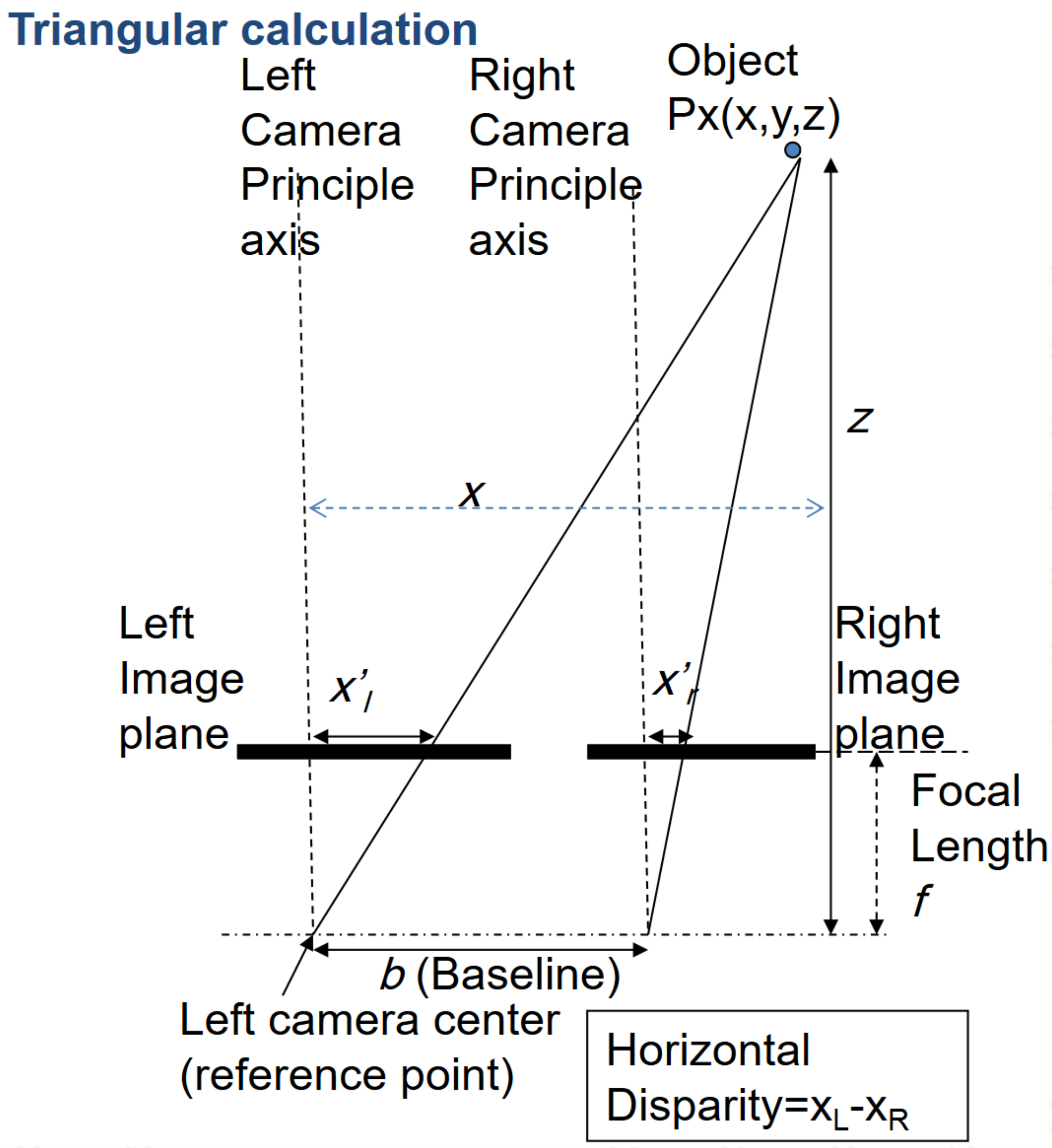
www.3pinmicro.com

https://www.youtube.com/watch?v=Qm7vunJAtKY

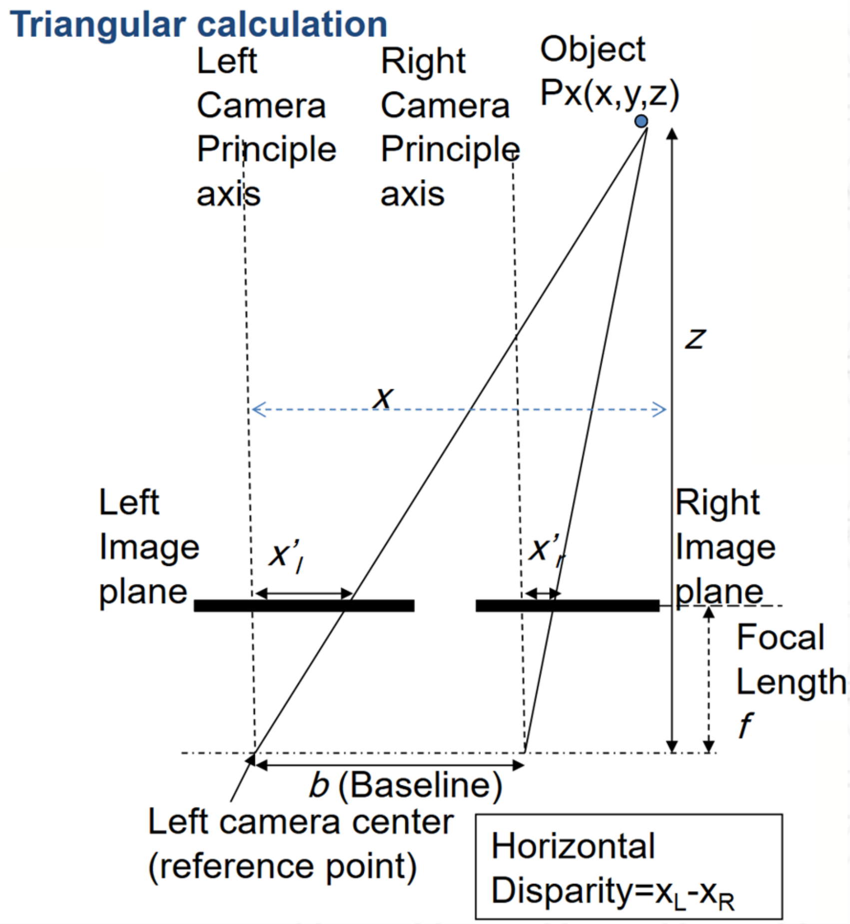
Depth with stereo camera



Depth with stereo camera



Depth with stereo camera



By similar triangle,
w.r.t left camera lens center

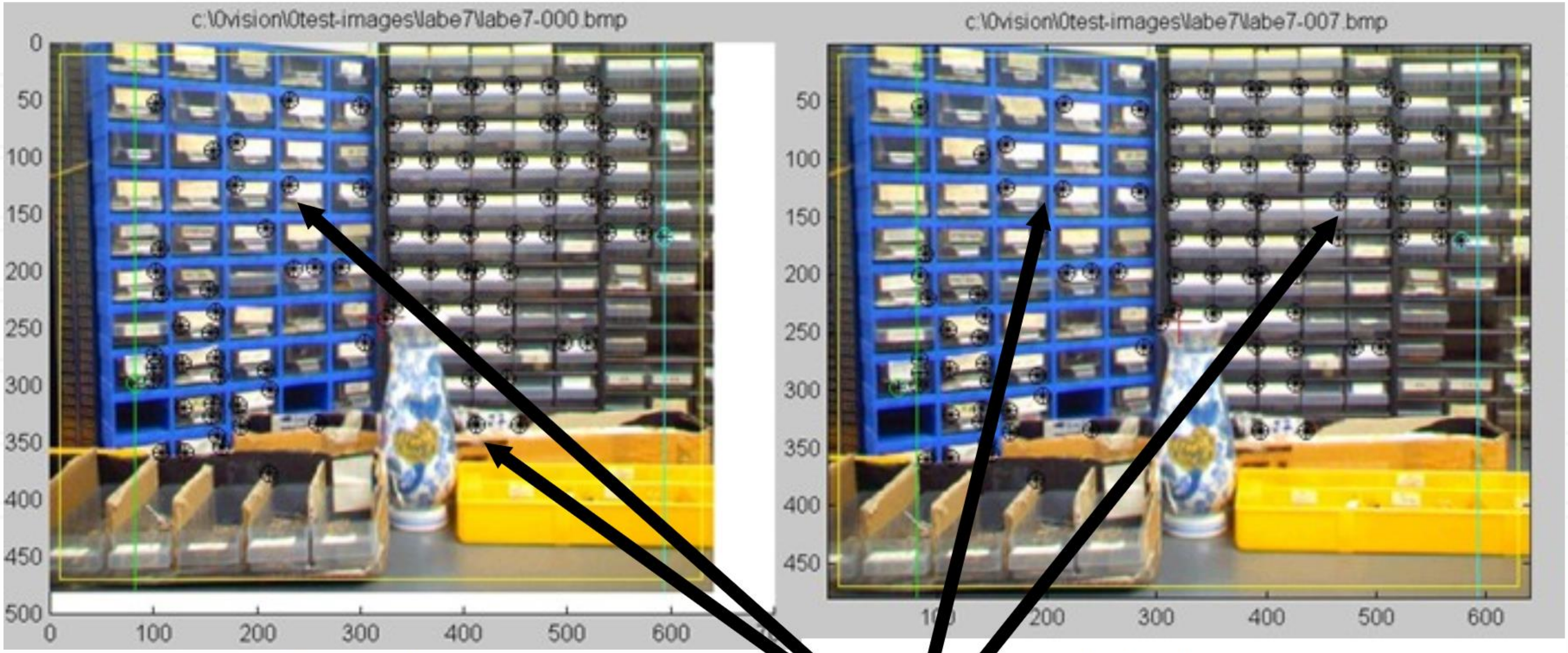
$$\frac{x}{z} = \frac{x_l'}{f},$$

$$\frac{(x - b)}{z} = \frac{x_r'}{f}$$

$$\text{elimate } x \Rightarrow z = \frac{f \bullet b}{(x_l' - x_r')}$$

Depth with stereo camera

- Requires finding corresponding objects on left and right images
- Can be computationally expansive and difficult on homogenous tissue



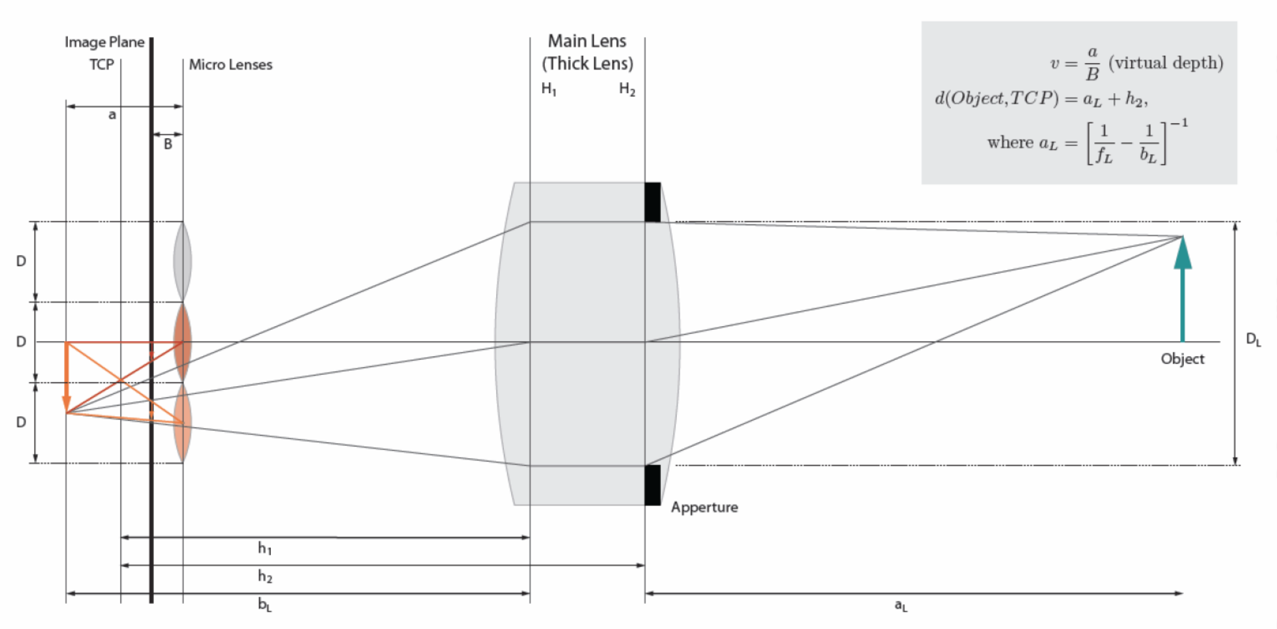
Left image

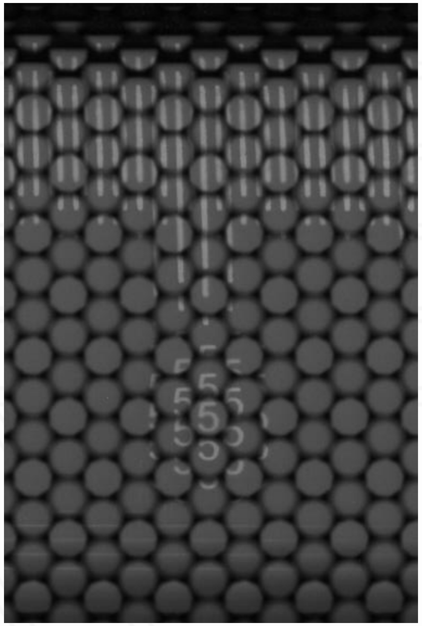
right image

Features are shown by overlaid markers on images

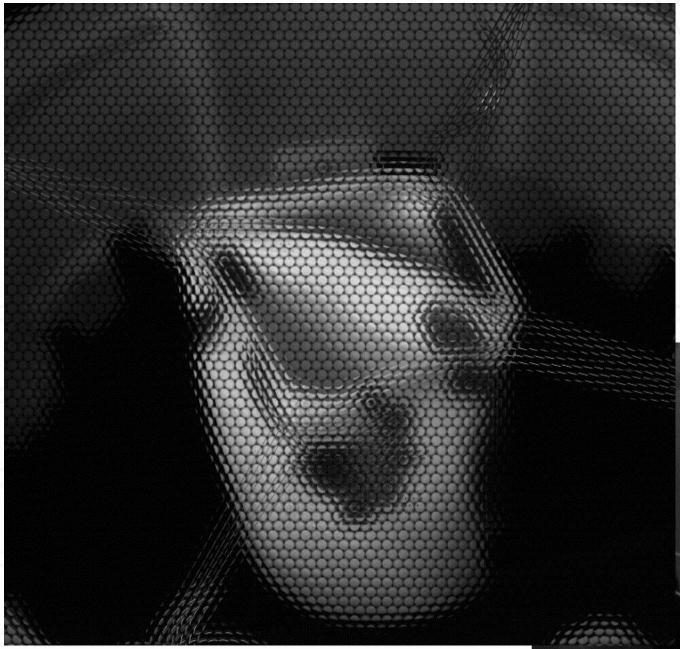
Depth with plenoptic camera

- 1 main lens (like a normal camera)
- An array of microlenses
- Depth is calculated from disparity between microlens images

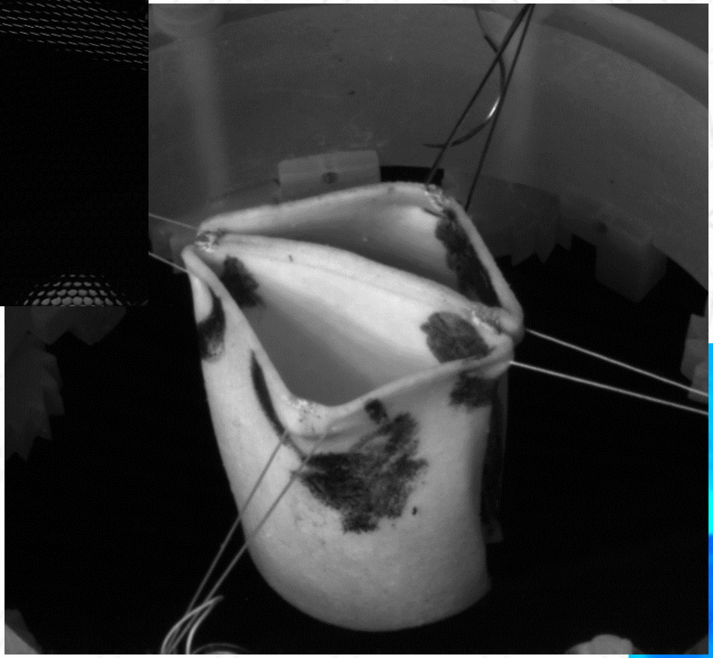




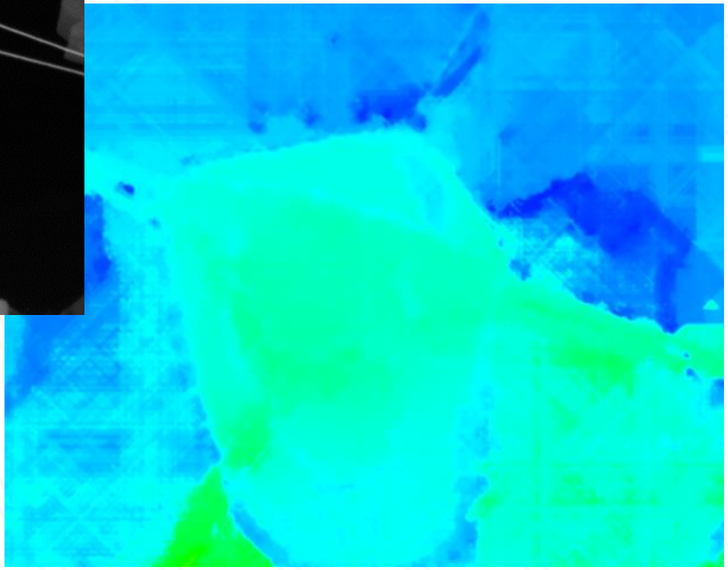
Depth with plenoptic camera



Raw microlens image



Total focus image



Calculated depth

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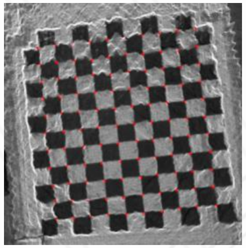
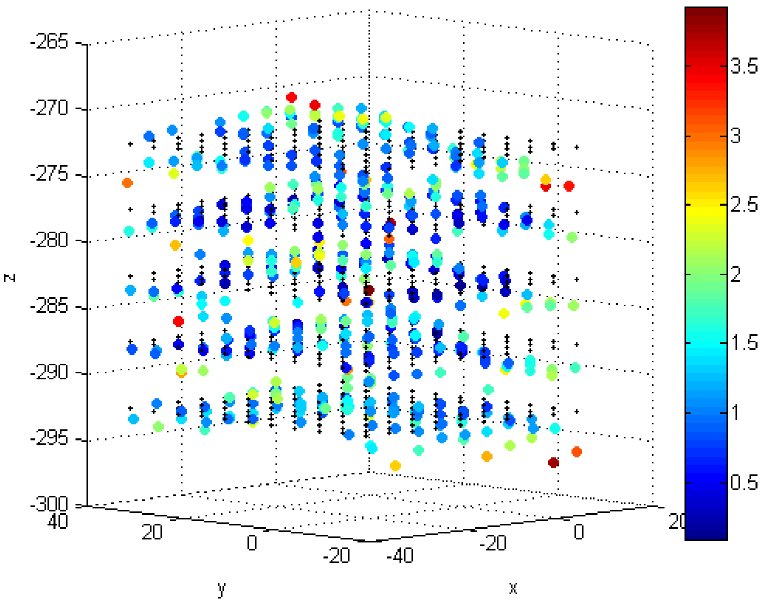
Plenoptic Camera: Accuracy Evaluation



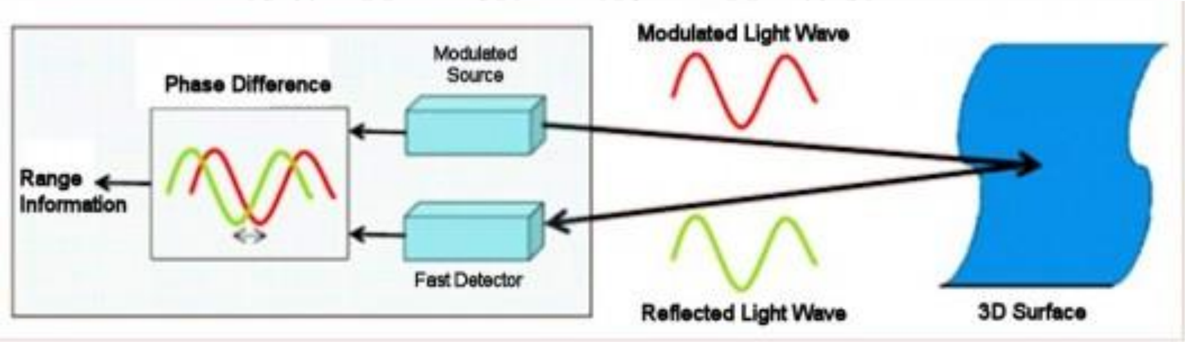
- Higher errors at edges
- Worst performance in Z



Ideal – grid reference	Mean Accuracy [mm]	Median Accuracy [mm]	Standard Deviation [mm]
Norm error	1.14	1.02	0.80
X error	0.49	0.48	0.30
Y error	0.13	0.12	0.11
Z error	1.02	0.89	0.73

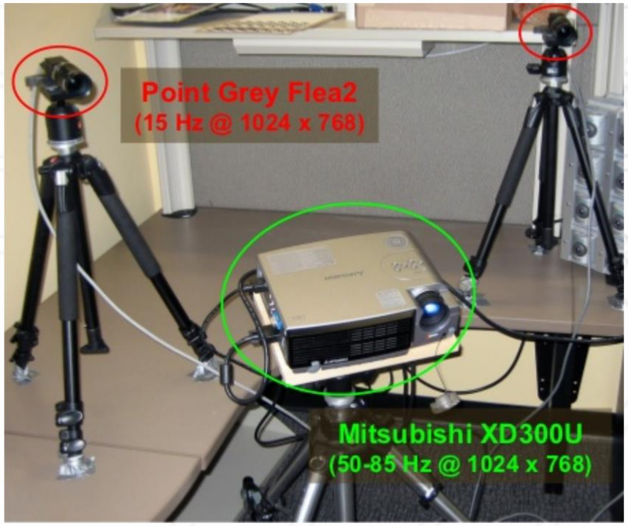
Time of Flight Camera

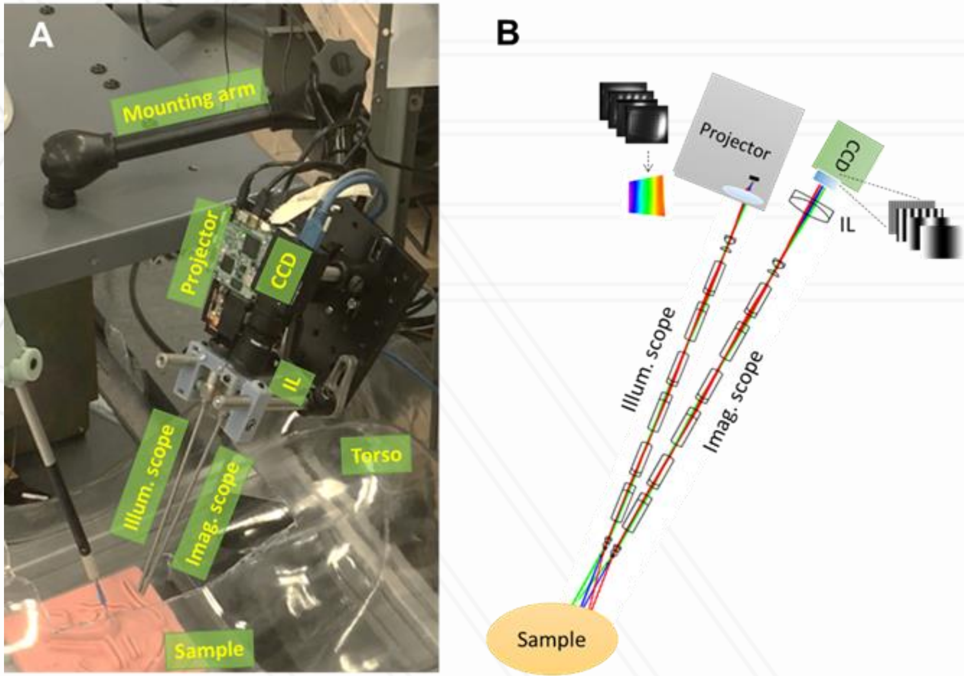
- Time-of-Flight
  - – Measures phase difference of modulated light from reference signal
  - – Noisy, systematic effects, typically lower resolution



Structured Light Camera

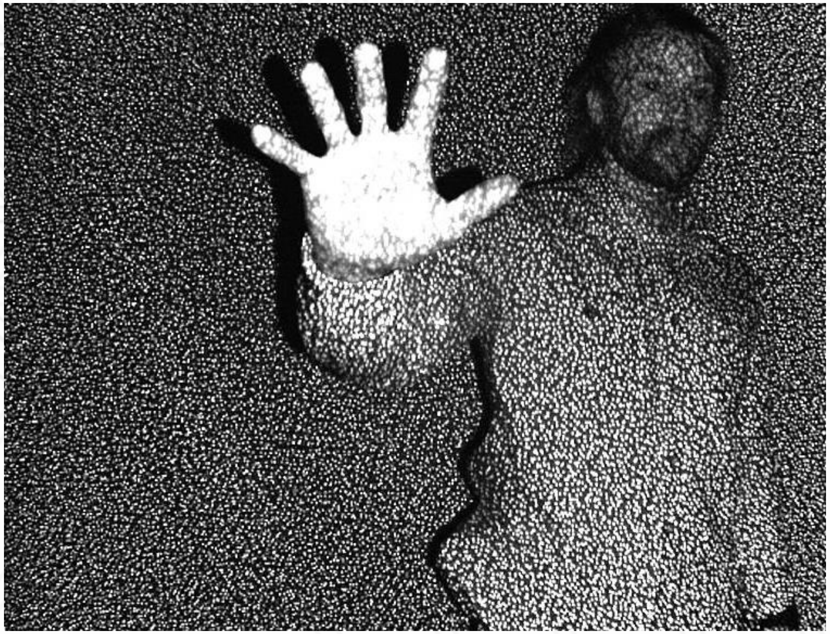
- Structured Light
  - Projection of known light patterns





Structured Light Camera

- Structured Light
  - Lines and dot patterns are common
  - Faster, can be robust on homogenous surfaces



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