Review:

Image Sensor: similar to the retina on the back of a human eye, measured in millimeters, and is about the size of a fingernail, made up of individual color sensors (called pixels)
Sensor Resolution: defined by the number of pixels on the Image Sensor
Focal Length: how far the image sensor is from the lens of the camera
Lens: where the light passes through to get to the image sensor, imagine this as a simple pinhole that is centered in front of the image sensor
Image Plane: an imagined image in front of the pinhole that is the same focal length distance as from the pinhole to the image sensor (this allows us to use an upright image, rather than an upside down image)
Stereo Vision: allows the robot to calculate the distance to nearby objects by using 2 cameras that are parallel to each other and the cameras are a known distance apart

Steps:

1. Take a picture – This step produces an image (a 2-dimensional representation of the real-world)
2. Process the Image – find interesting points such as corners and edges of objects in the image – we'll call these interesting points, features
3. Calculate information – Use the features to extract information about the scene in the image such as where objects are, or distance to particular features or which objects are in view.

Line through two points:

$$z - z_c = \frac{f - z_c}{A_x - x_c}(x - x_c)$$

- ➢ x_c , z_c is the center of the camera – typically one camera will be set at the origin and is 0,0, the other will typically have the x position as the offset between the two cameras.
- ➢ A_x is the position in mm of the pixel of the feature in the image – find by multiplying the number of pixels from center by the ratio of sensor size to pixel count (i.e. if the sensor is 2000 px wide and 10 mm wide than the ratio would be 200 px per mm).
- ➢ For the both cameras, if the pixel of the feature in the image is to the left of center, than the value will be negative.
- ➢ You will have two equations with z and x in them. Solve by substitution, or by systems of equations.

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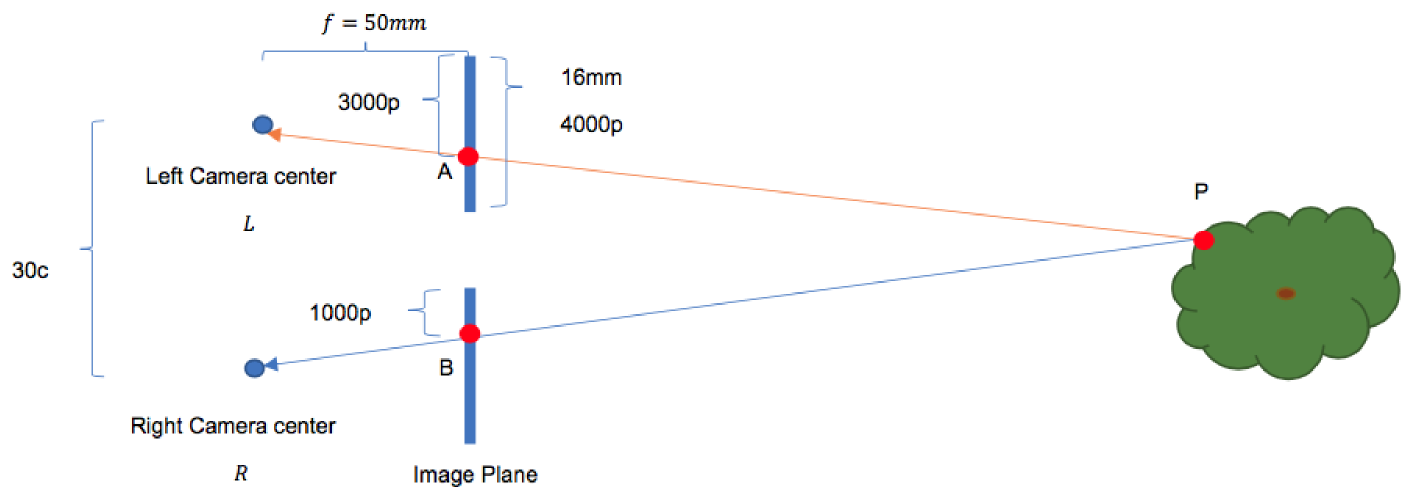
Challenge Questions:

A robot with a stereo camera pair mounted **30** cm apart, with **50** mm focal length and a sensor that is **16** mm wide with **4000** horizontal pixels. If a feature on an object is located at an x-coordinate of **3000** on the left camera and at an x-coordinate of **1000** on the right camera, how far in front of the robot is the object?



Set the left camera as the origin

$$(x_L, z_L) = (0, 0)$$

The the right camera center coordinates will be:

$$(x_R, z_R) = (300mm, 0)$$

Each camera sensor is 4000 pixels wide and thus 2000 pixels from the edge to the center
Each camera is 16mm wide and thus 8mm from the edge to the center

Converting feature x-location from pixels to mm

$$Left\ camera:\ A_x = [(3000 - 2000)pixels] \cdot \frac{8mm}{2000pixels} = 4mm$$

$$Right\ camera:\ B_x = [(1000 - 2000)pixels] \cdot \frac{8mm}{2000pixels} = -4mm$$

However, since the right camera is 300mm to the right, the true x-location of the feature in B is

$$B_x = -4 + 300 = 296mm$$

The ray from the object to the left camera center (L) passes through point A
Using the equation for a line through two points (L and A):

$$z - L_z = \frac{f - L_z}{A_x - L_x}(x - L_x)$$

$$z = \frac{(50-0)}{(4-0)}x = \frac{50}{4}x = 12.5x$$

The ray from the object to the right camera center (R) passes through point B.
Using the equation for a line through two points (R and B):

$$z - R_z = \frac{f - R_z}{B_x - R_x}(x - R_x)$$

$$z = \frac{(50-0)}{(296-300)}(x - 300) = -12.5(x - 300)$$

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Setting the two equations for z equal to each other:

$$12.5x = -12.5(x - 300)$$
$$12.5x = -12.5x + 3750$$
$$25x = 3750$$
$$x = 150mm$$

$$z = 12.5x$$
$$z = 12.5 \cdot 150$$
$$z = 1875mm$$

Thus the object is 1.875 meters from the robot

Why does the accuracy of this method become worse as the objects move farther away? It may help to think about what the distance is if the objects are 1 pixel from the center versus 2 pixels from the center?

At far ranges very small changes in pixel position result in large changes in distance

If the pixel was at the center of both cameras, it would be an infinite distance away

If it were one mm inform the center, they would intersect at some point p that we can calculate the z coordinate as before

$$z - L_z = \frac{f - L_z}{A_x - L_x}(x - L_x) \qquad z - R_z = \frac{f - R_z}{B_x - R_x}(x - R_x)$$

$$left\ camera:\ z - 0 = \frac{f - 0}{1 - 0}(x - 0)$$
$$right\ camera:\ z - 0 = \frac{f - 0}{-1}(x - d)$$
$$\frac{f}{1}x = \frac{f}{-1}(x - d)$$
$$fx = -fx + fd$$
$$2fx = fd$$
$$x = \frac{d}{2}$$
$$z = fx = \frac{fd}{2}$$

Now if we look at the case where the pixel was 2mm in from the center

$$left\ camera:\ z - 0 = \frac{f - 0}{2}(x - 0)$$
$$right\ camera:\ z - 0 = \frac{f - 0}{-2}(x - d)$$
$$\frac{f}{2}x = \frac{f}{-2}(x - d)$$
$$\frac{f}{2}x = -\frac{f}{2}x + \frac{fd}{2}$$
$$fx = \frac{f}{2}d$$
$$x = \frac{d}{2}$$

$$z = \frac{f}{2}x = \frac{fd}{4}$$

We see that with a small change in pixel position, the range drops in half

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