Advanced Vision Guided Robotics

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Traditional Vision vs. Vision based Robot Guidance

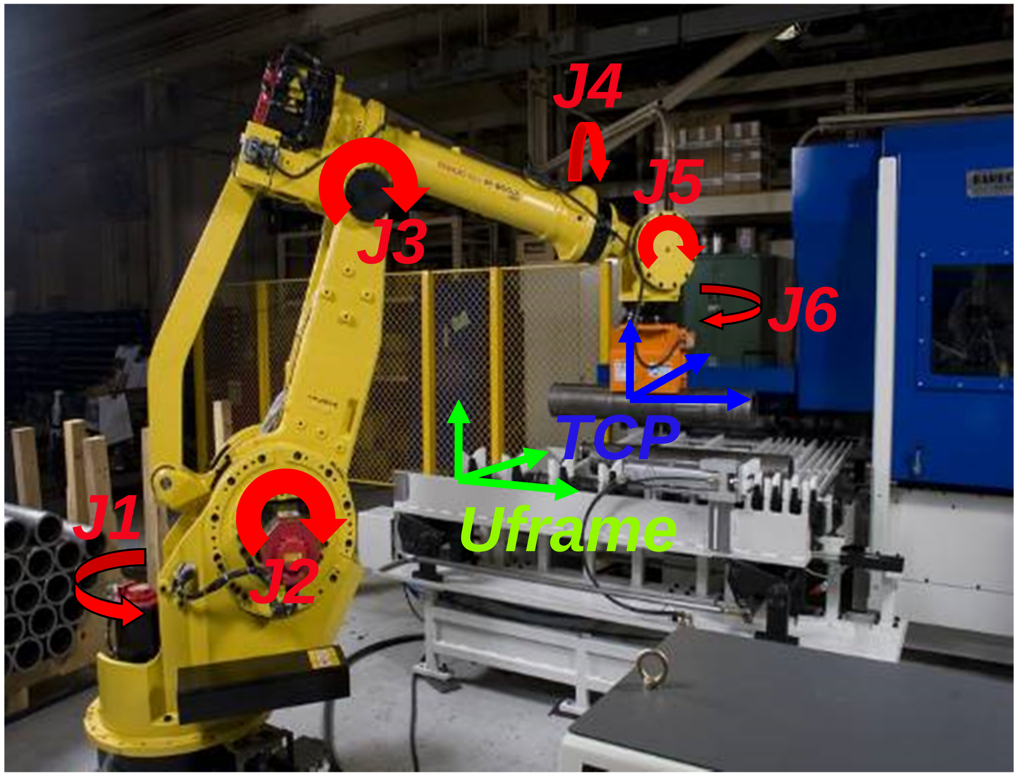
- Traditional Machine Vision –
  - Determine if a product passes or fails
    - Assembly Verification
    - Find Defects
    - Gauging/Metrology

- Vision Guided Robots –
  - It all about location,
    - Locate and pick parts
    - Locate and move relative to parts for assembly
    - Locate parts and remove flash or apply epoxy

Robotic System Adaptability

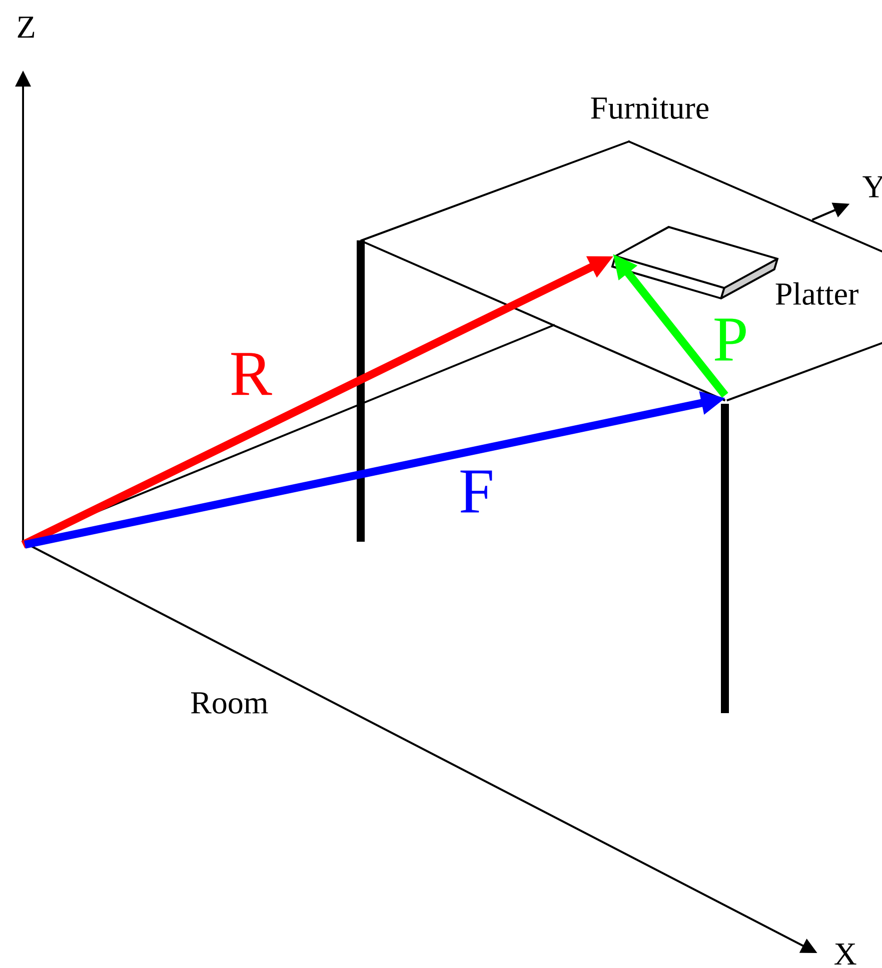
- Basic Premise:

  Vision Guidance is needed when the part is not always in the same position

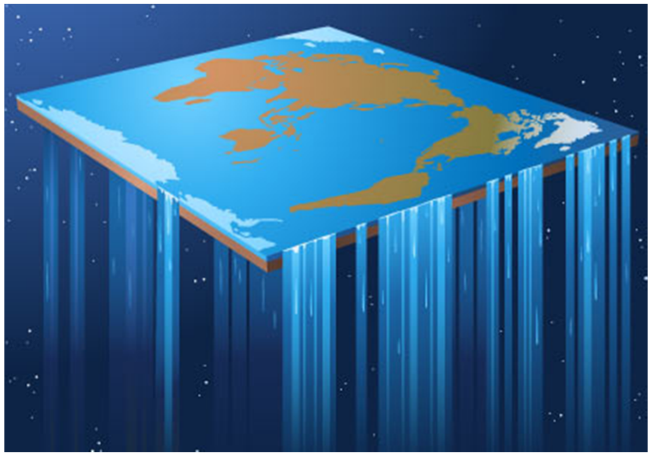


Position Relationships

- Start with a Cartesian coordinate system for rendering position (X,Y,Z)
- **R** is the position of the platter relative to the room.
- **F** is the position of the furniture in the World coordinate system.
- **P** is the position of the platter in the furniture frame or furniture coordinate system.
- Now consider a table where adjacent legs are shorter and a platter where one side is significantly tilted



The world is not flat…



- Traditional cameras see a flat world – 2D and flat

- Robots work in the real world and must compensate for a parts position with 6 degrees of freedom

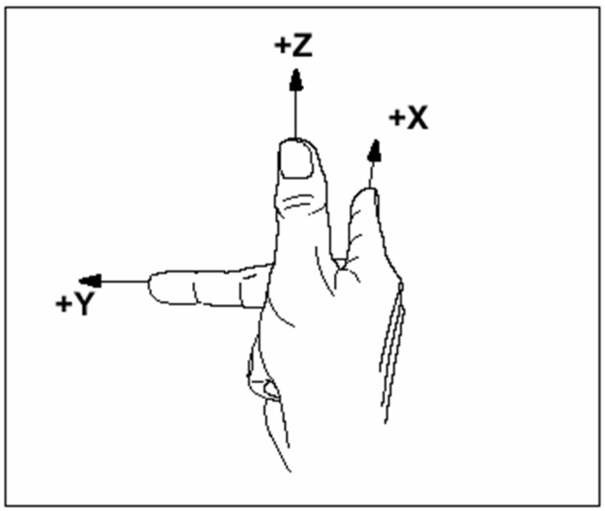
Cartesian Coordinates

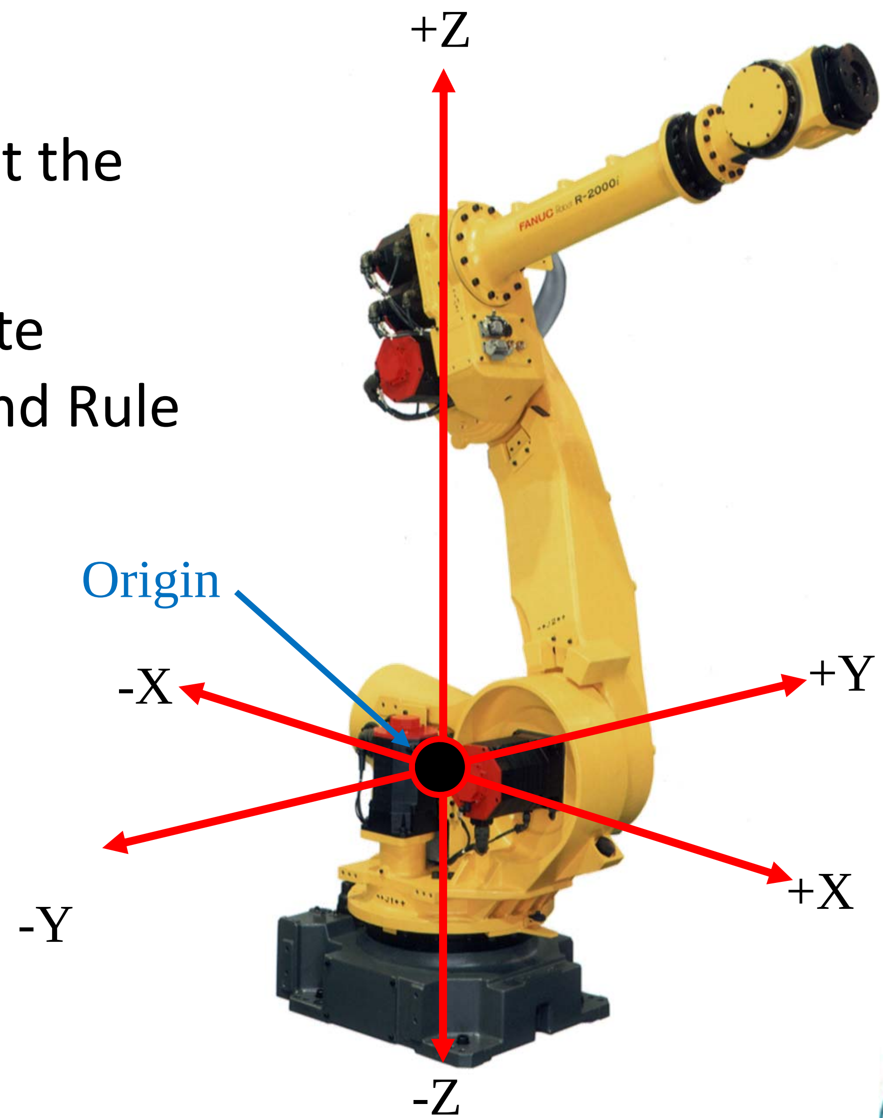
- Consider the Robots Face Plate Position with respect to a part (X,Y and Z)
- Now consider a plane pivoting around this point. Rotating around X,Y and Z.
- This is part positioning with 6 degrees of freedom.
- Our ultimate goal:

  How can vision be used to guide the robot to the position of a part?

World Frame

- World frame has its origin at the intersection of axes 1 and 2
- Aid to Remember Coordinate Relationships: the Right Hand Rule

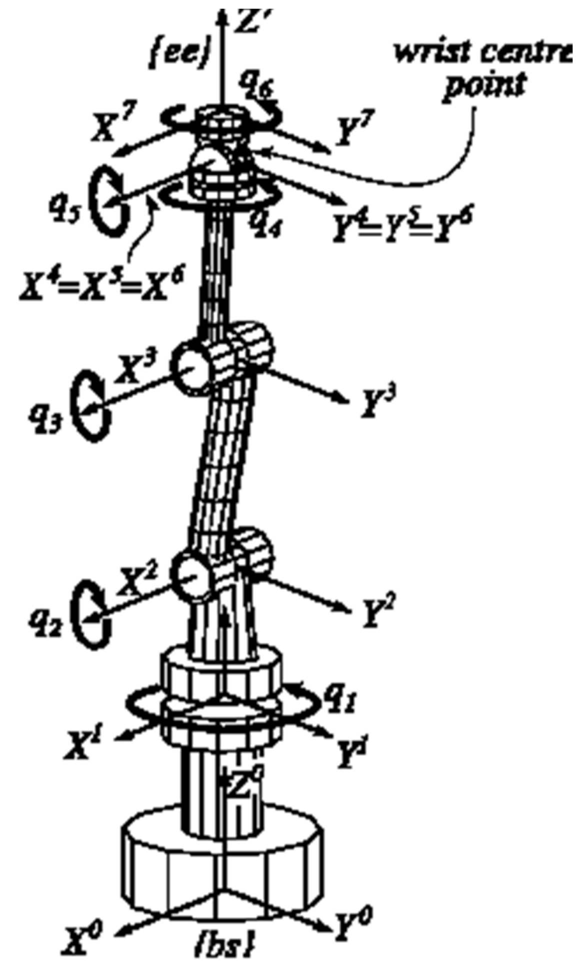




Joint to Cartesian Space

- **Robot kinematics** is the study of the motion (kinematics) of robots. In a kinematic analysis the position, velocity and acceleration of all the links are calculated without considering the forces that cause this motion.

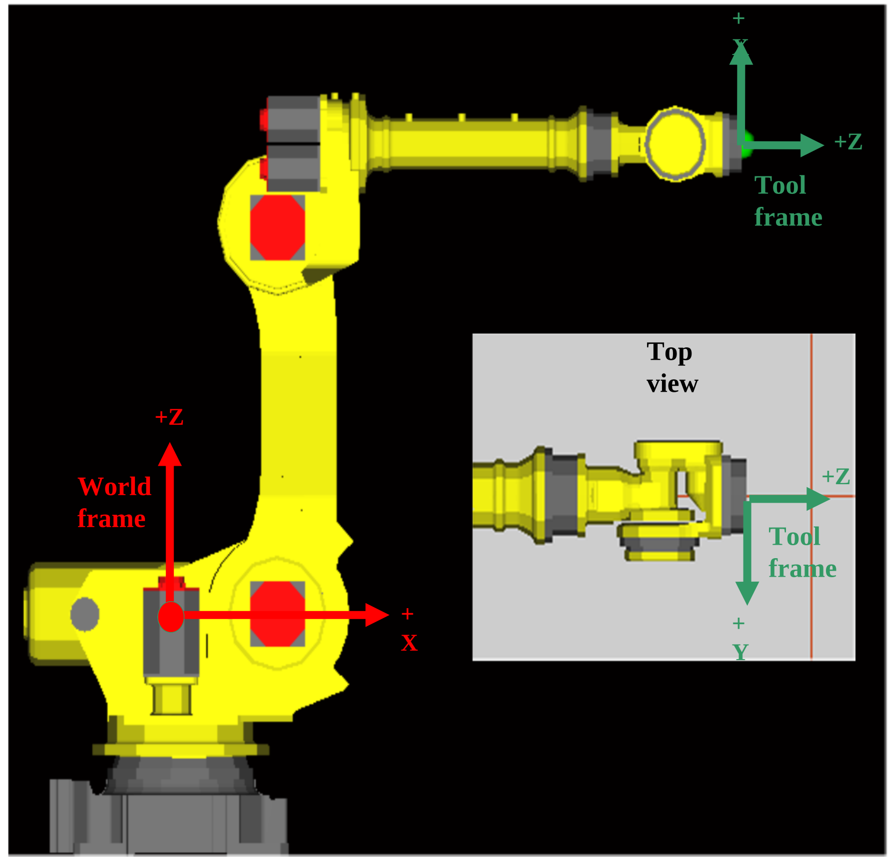
- Joint angles (provided by encoders) and arm segment lengths are combined to render position and orientation



-1 Reference Wikipedia

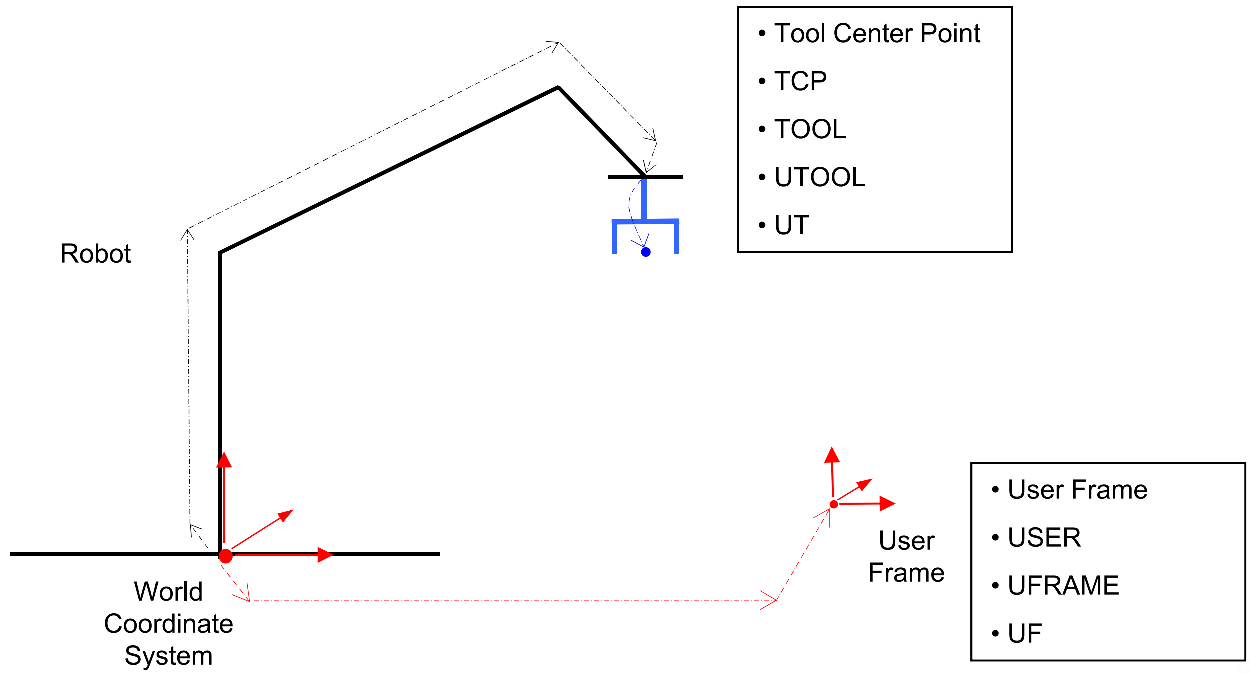
World and Tool Frames

- Two Key Contributors to the Robots Position
  - User Frames
    - The Primary Robot position Coordinate system is referred to as the World Frame
    - Other frames can be created that are positioned relative to the world
  - Tool Frames
- Using kinematics, the world frame and tool frame, the robot can be used to create positions and establish planes



Frames Important to Vision

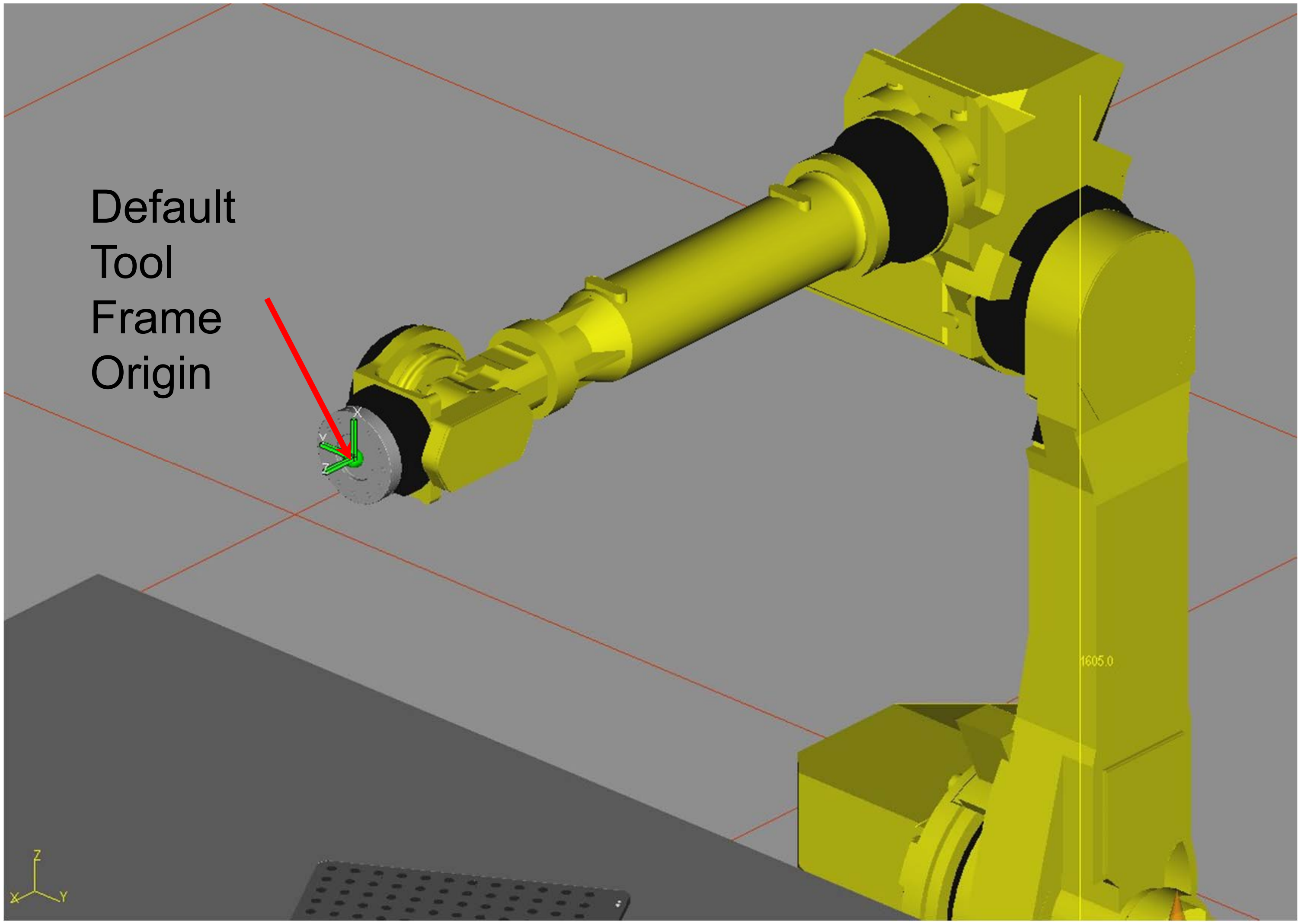
- World frame - default frame of the robot
- User frame - user defined frame
- Tool frame - user defined frame



Tool Frame

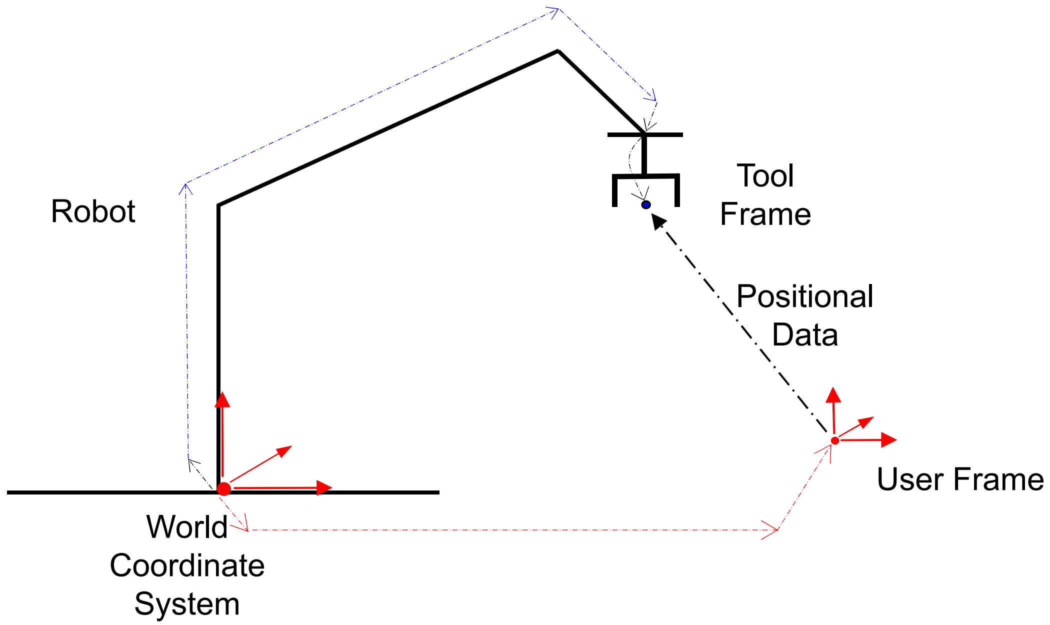
- Origin is called the Tool Center Point or TCP
  - Defines location of where work is done
- Default location is center of the faceplate
- Origin of the tool frame must be offset to a fixed point on the physical tool
- All offset measurements for the Tool Frame are relative to origin of the Face Plate

Default Tool Frame



Tool Frame and Programming

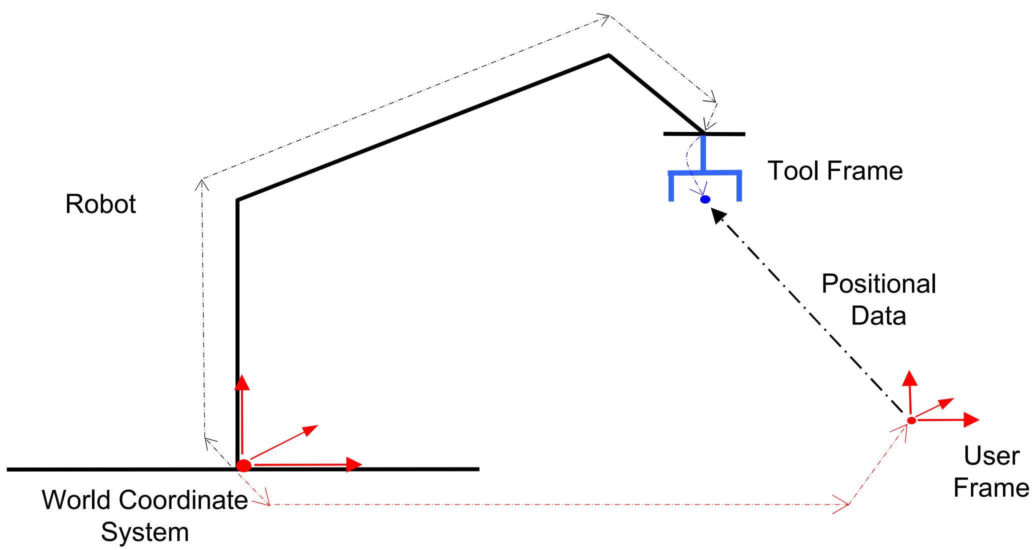
- When a point is recorded, it references both the Tool Frame and the User Frame



- The Tool Frame is what the robot “looks at” when you ask it to do a Linear or Circular movement.

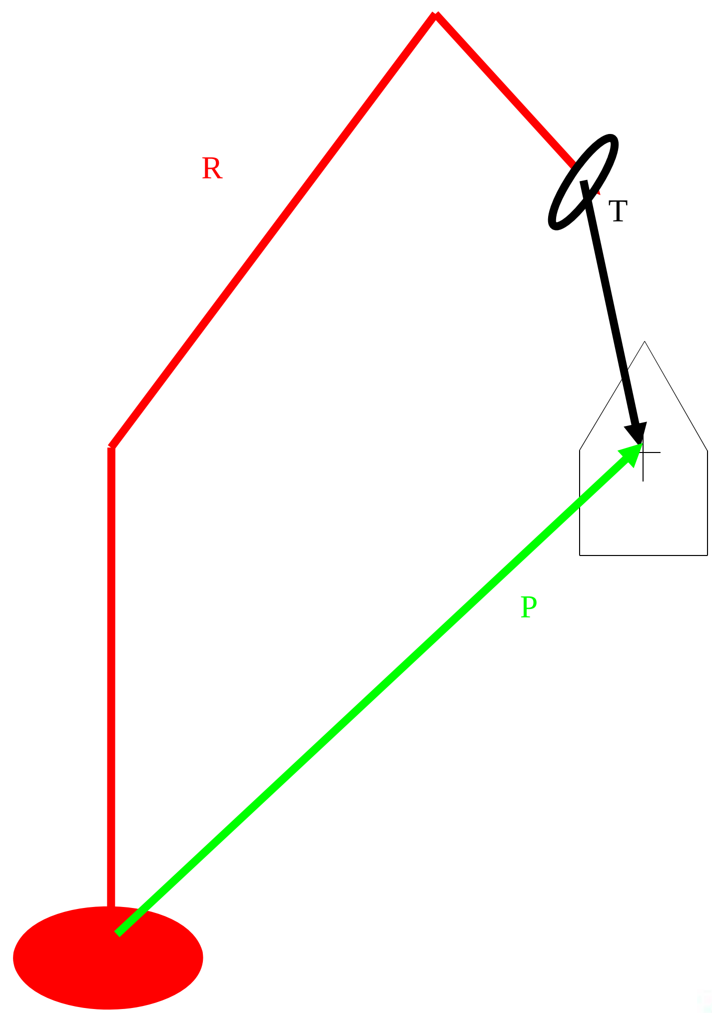
User Frame

- User Frames are based off of the World Frame
- They can be taught at any location and any orientation
- Positions are taught with respect to a User Frame (as well as a Tool Frame)



Robot and Tool Positions Relative to the Part

- The robots position and orientation is reported with six degrees of freedom
  - X,Y,Z, Pitch, Yaw, Roll
- The tool has a position and orientation, too.
- Robot and Tool frames are combined to find a position relative to the part.
  - This relationship is resolved before moving the robot the part.



Simple Camera Calibration

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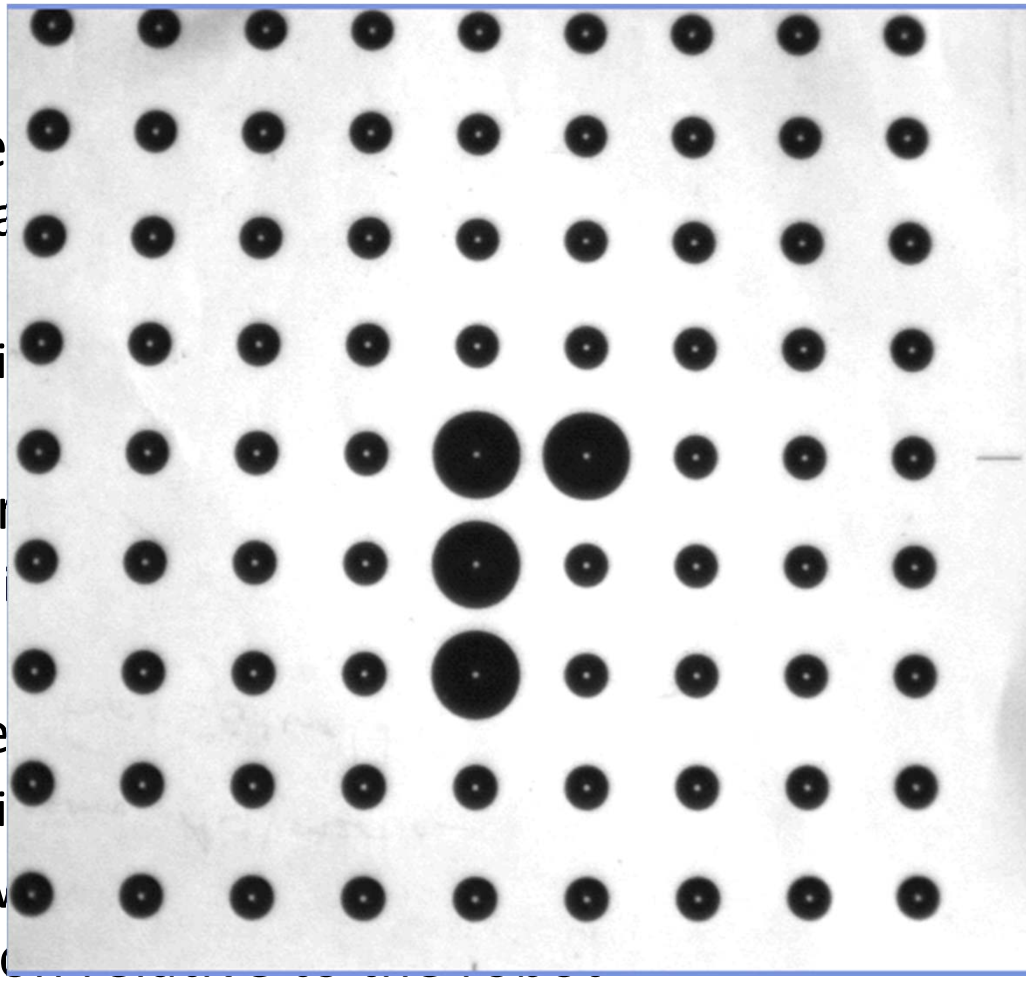
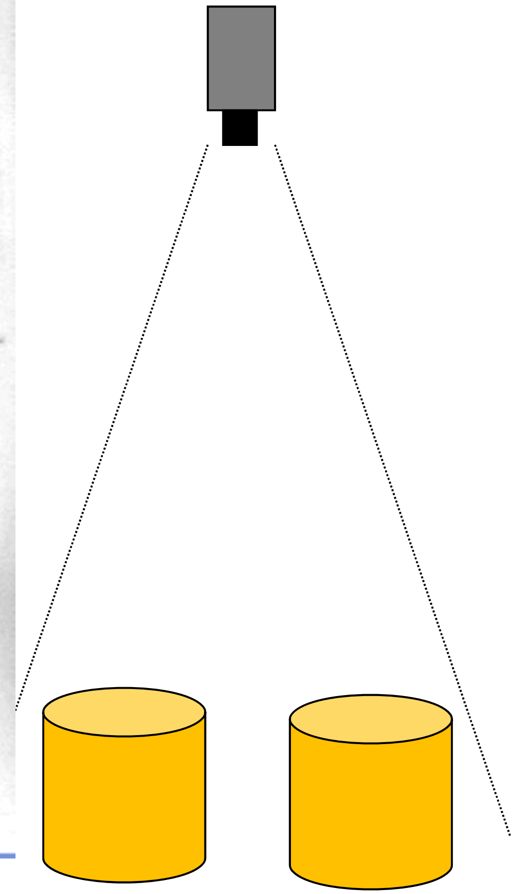
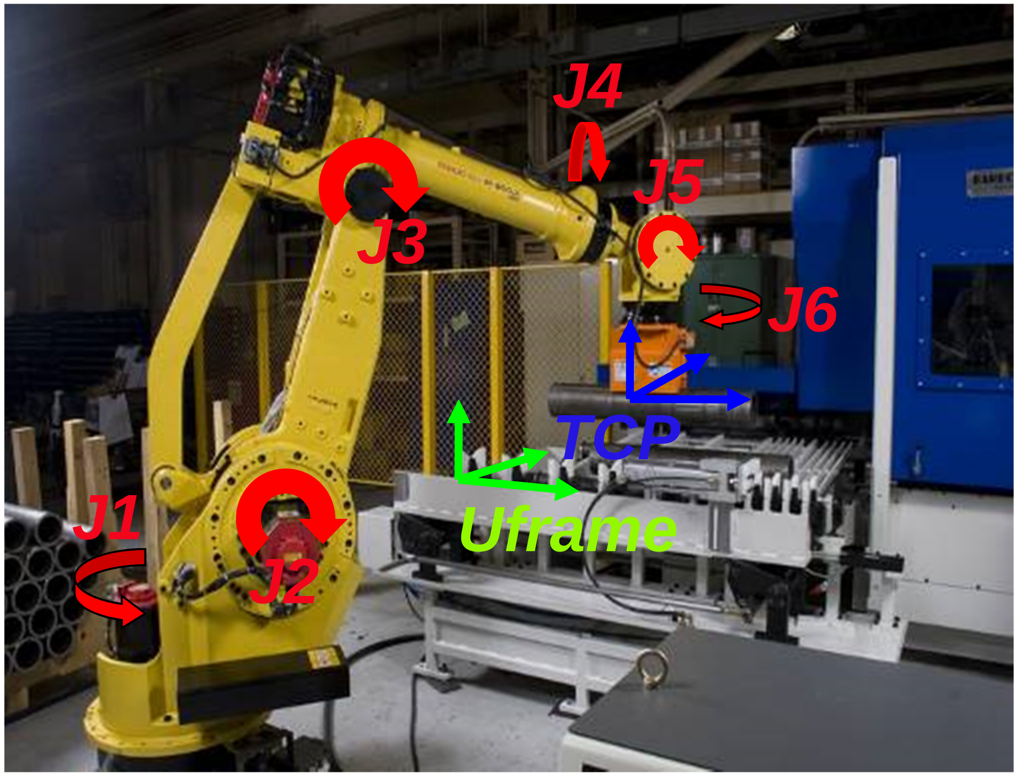




Robot to Part Relationship

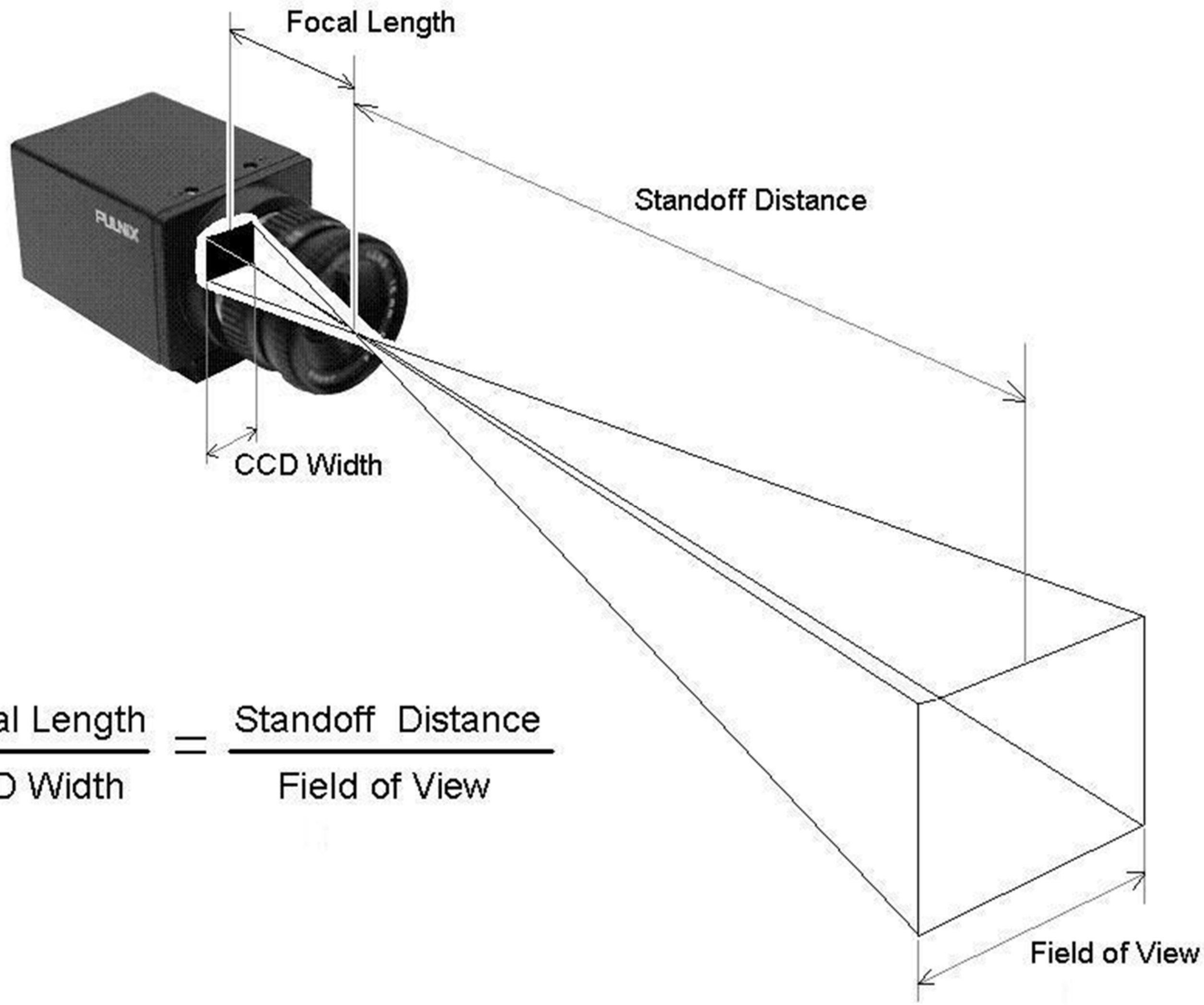
- **Three elements to Robotic system accuracy**
  - **Robot Mastering**
  - **TCP or Tool Center Point**
  - **User Frame or Fixture**



Position Relationship Summary

- Start with a well mastered robot
  - Joint angles and Kinematics create a good World Frame (Joint angles translated into to Cartesian Coordinates)
- Create reference positions of the calibration grid to the robot
  - Where is the grid in robot space? The Origin, X and Y directions
- Calibrate the vision system to:
  - Tie the calibration grid position and orientation to what is seen by the camera
  - Render pixels per unit of measure

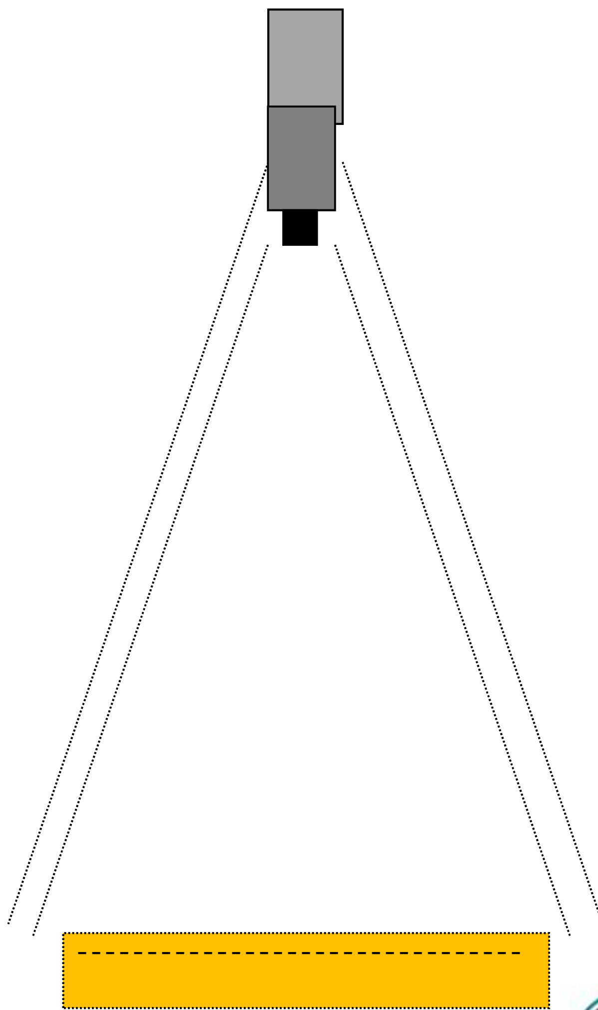
Lens Calculations



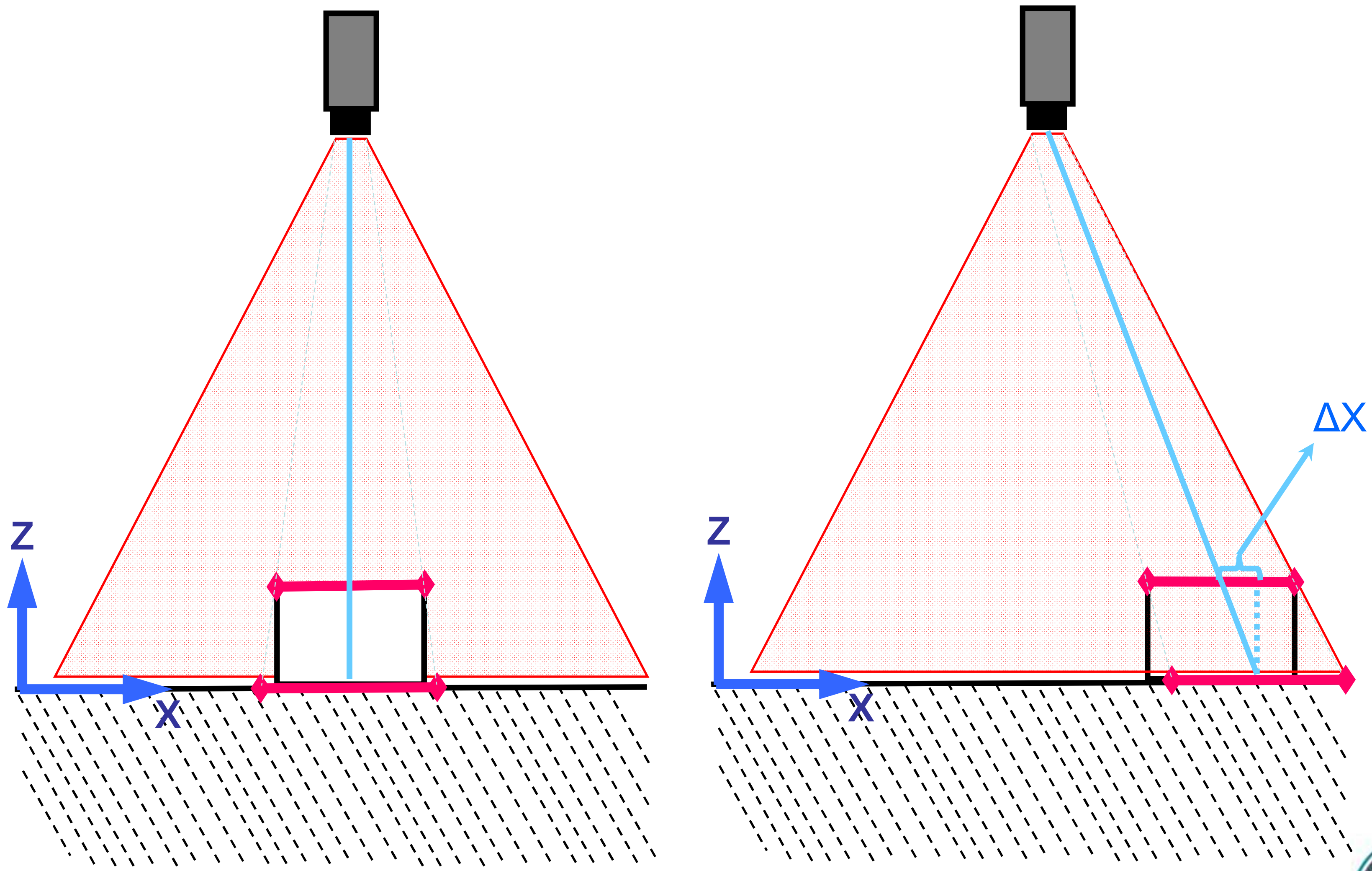
$$\frac{\text{Focal Length}}{\text{CCD Width}} = \frac{\text{Standoff Distance}}{\text{Field of View}}$$

Simple 2D Calibration with a Change in Z

- The image created by the camera is like looking through a Cone
- The ratio of Pixels to Units of Measure changes as you move within the cone
- If the part distance from the camera is not identical to when the camera was calibrated, finding a parts position accurately requires adjustment of the transformation.
- What to leverage?
  - Part Size, multiple calibrations or lens mathematics

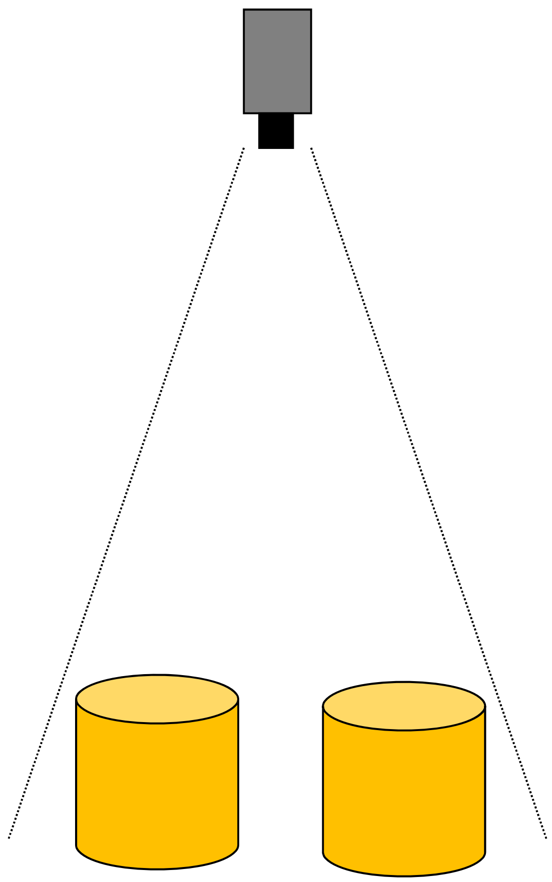


Part Height Variation Problem

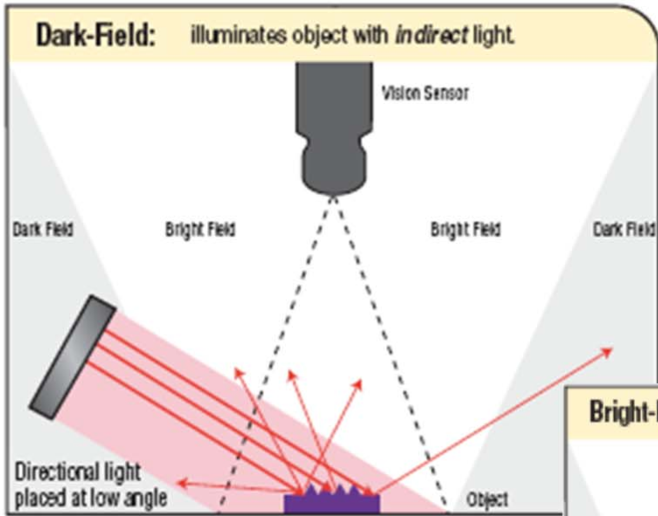


Basic Cameras are 2D

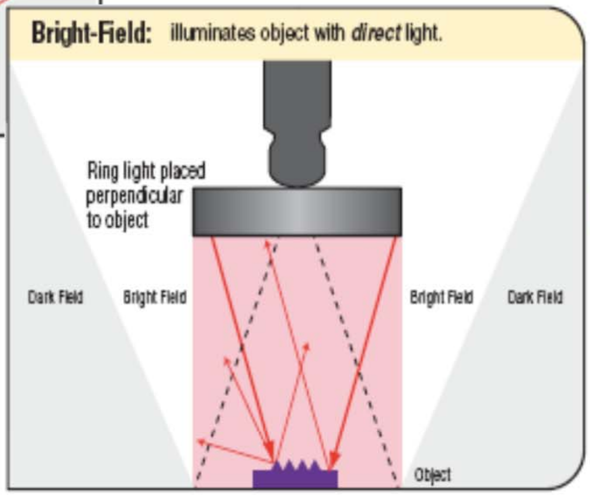
- What aspects of a parts position relative to the robot can we determine solely from a 2D image?
- Variables that you may need to know:
  - Distance from the camera
  - Magnification of the lens
  - Size of the part
  - Calibration (EG: pixels/mm)
  - Orientation of the camera in space
  - Orientation of the robot in space
- How does the distance away from the camera effect the part position calculation?

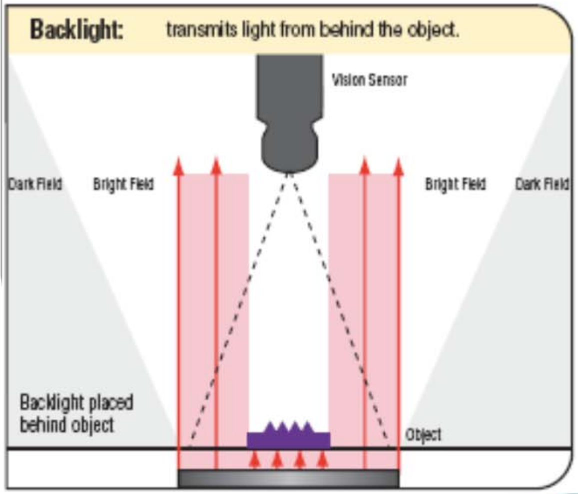


Lighting Impacts Part Position (Perspective)



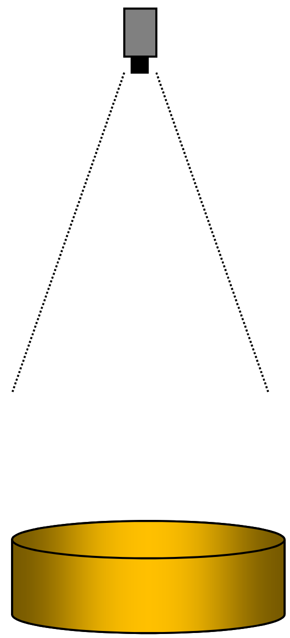
- Perceived location of a part can shift due to lighting
- Locate the center of the top surface



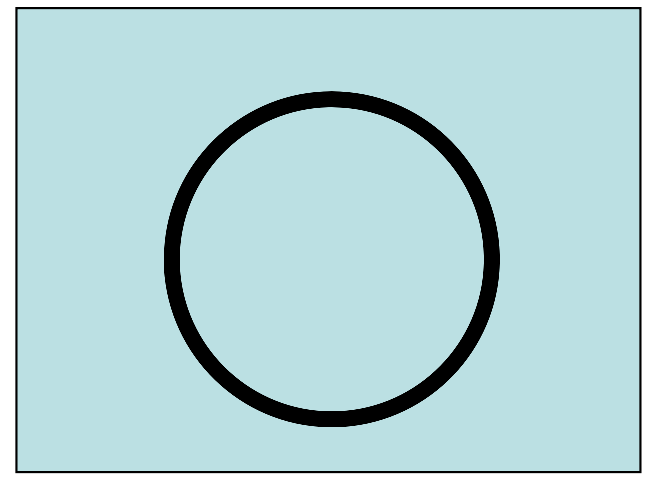


- Which lighting method provides stable features for the vision system to locate?

2D Single Camera - 2.5 D

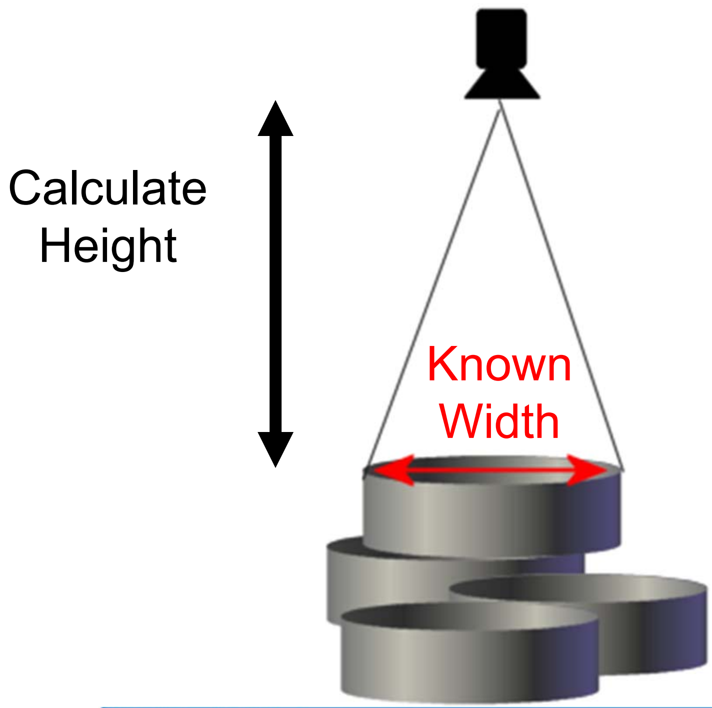


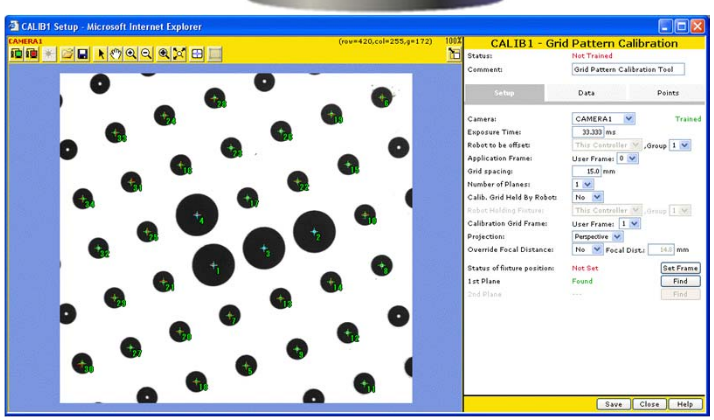
Camera Image



- Height change creates subtle apparent size change.
- Are you sure the part size is not different – creating the same affect?

Use Focal Length to Calculate Distance





Knowns:

- Calibrated Focal length of Lens
- Camera Array size
- If Part size is known, calculate distance of the part from the camera

Depth Using Consistent Part Size

- Find parts at two known heights and set data.
- This will define scale, layer, and height relation.

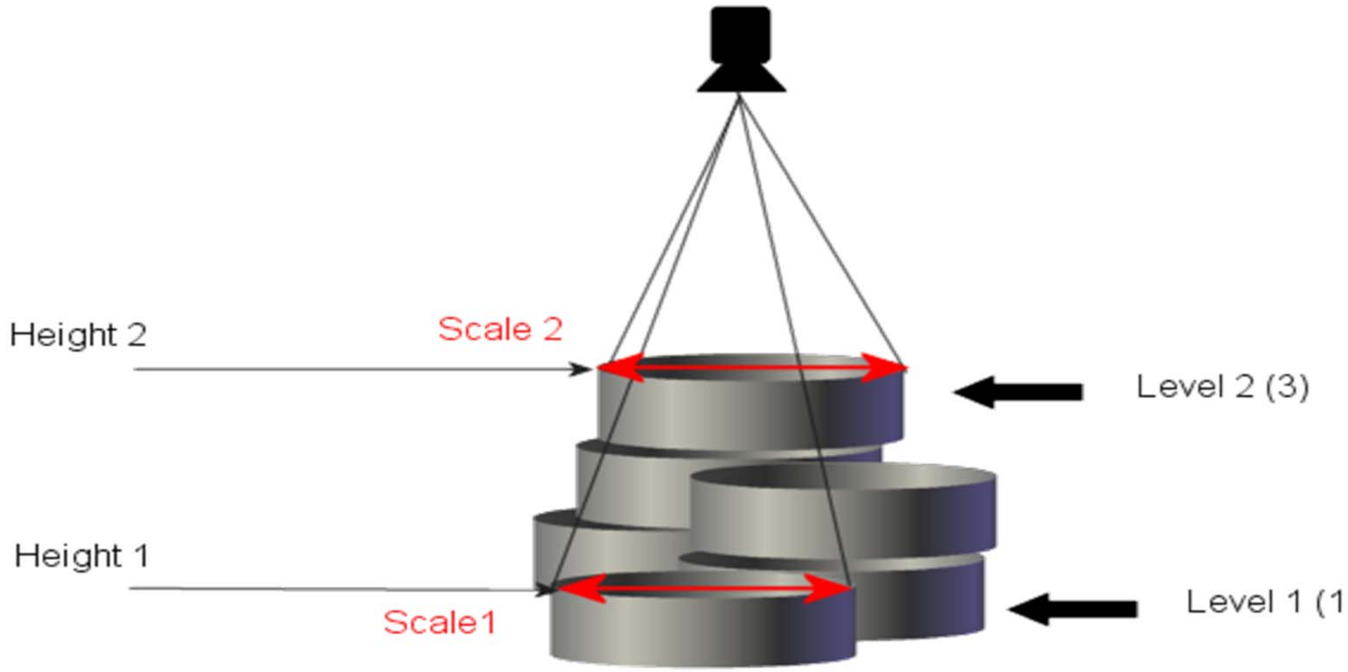
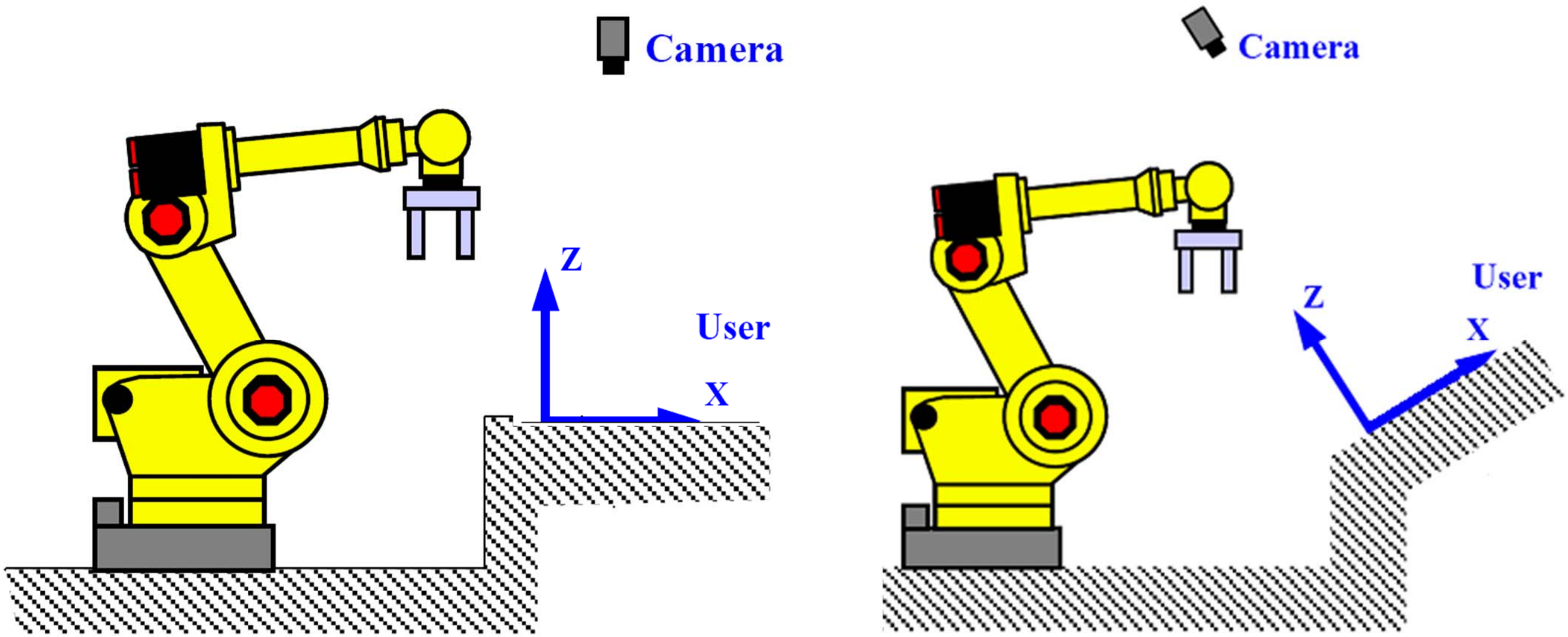


Image to Robot Relationship



In two-dimensional applications, the XY plane of the user frame specified here should be parallel to the target work plane.
How do you compensate when this is not the case?

Vision To Robot Transformations Considerations

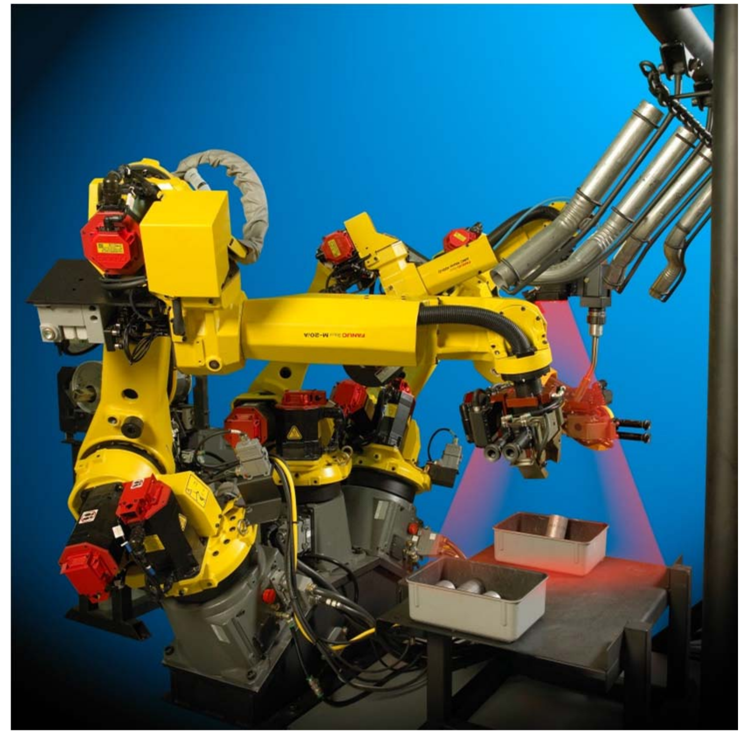
- Camera mounting style
  - Fixed position or Robot mounted camera
    - Cycle time
    - Size of part (FOV) vs. accuracy needed
- Part Presentation issues
  - In which axis's is the part likely move?
    - X, Y, Rotation, Z, Pitch and Yaw
  - Is the part consistent or is its presentation consistent
  - Is it possible to correlate position from different perspectives?
  - Can structured light be used to help identify location?

2D Robotic Assumptions

- 2D imaging systems can be used if:
  - The part always sits flat on a surface or fixture (no pitch or yaw changes)
  - The part is consistent in its size and shape
  - The tool is designed to compensate for any variation in height (and subsequent X, Y error)
- 2D is not a good solution when:
  - Parts are stacked and may be subject to tipping
  - Parts are randomly placed in a bin for picking
  - Parts enter the robot cell on a pallet that is damaged, or on a conveyor that wobbles
  - High accuracy assembly process like hanging a door on an automobile

Example 3D Robot Applications

- Racking and Deracking
- Palletizing and Depalletizing
- Welding uneven surfaces
- Grinding and flash removal
- Machine load
- High accuracy assembly
- Parts on Hangers
- Picking Stacked parts
- Picking parts randomly located in bins

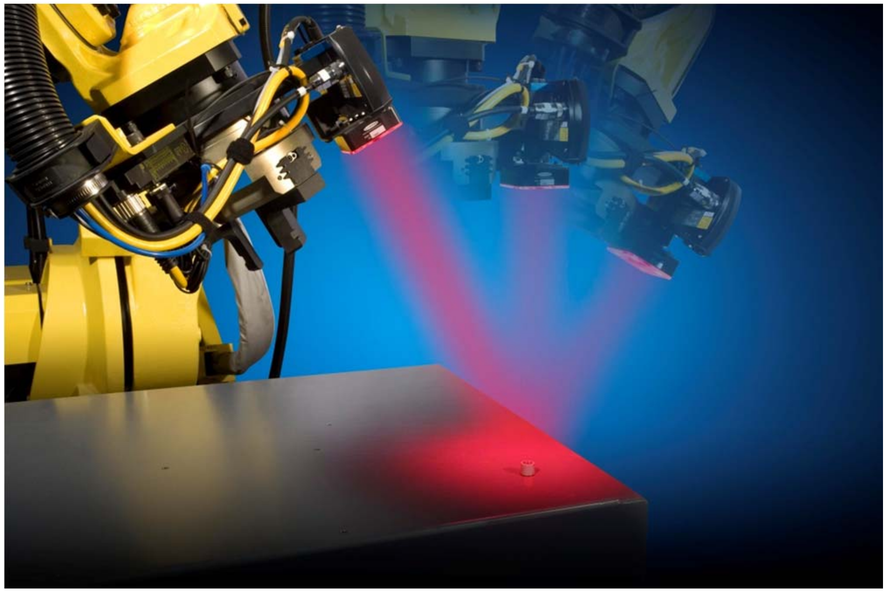


Common Methods for 3D Vision Position Extraction

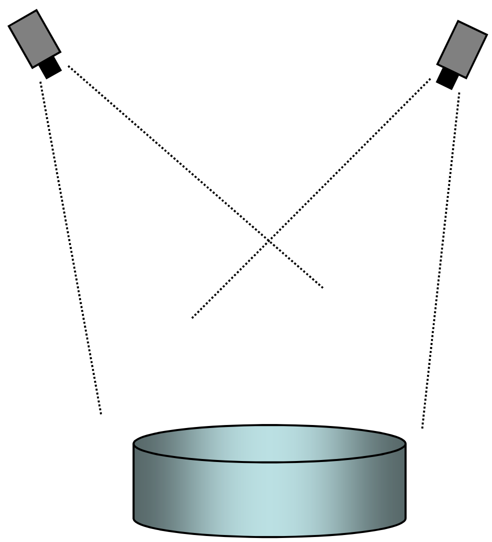
- 2 ½ D – Use Scale changes to calculate Z Height
- Use known geometric relationships to calculate position
- Stereo Triangulation
- Structured Light
- Interferometry
- Laser Triangulation
- Time of Flight Imaging

Stereo Method

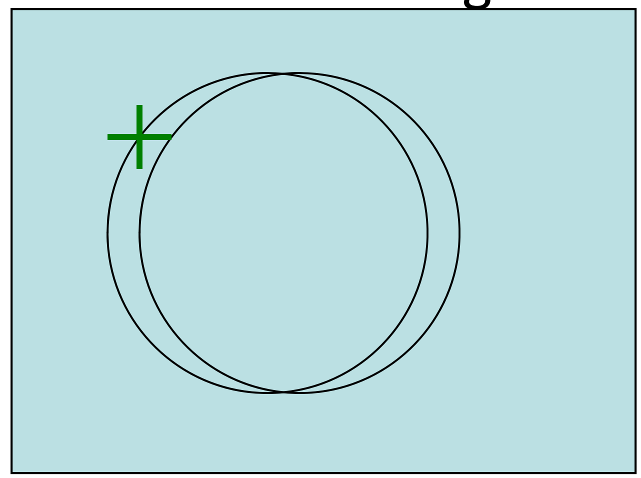
- Camera Pixels represent rays originating at the cameras lens
- Multiple rays converge to form points X,Y and Z
- Multiple Points form a plane (at least 3 points are required)



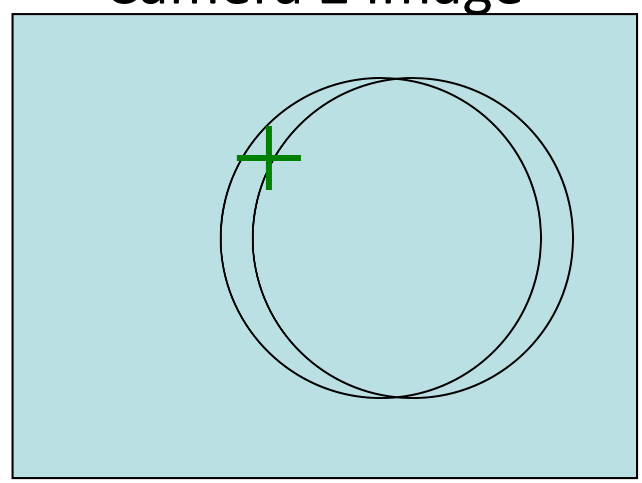
Stereo Triangulation Method



Camera 1 Image



Camera 2 Image

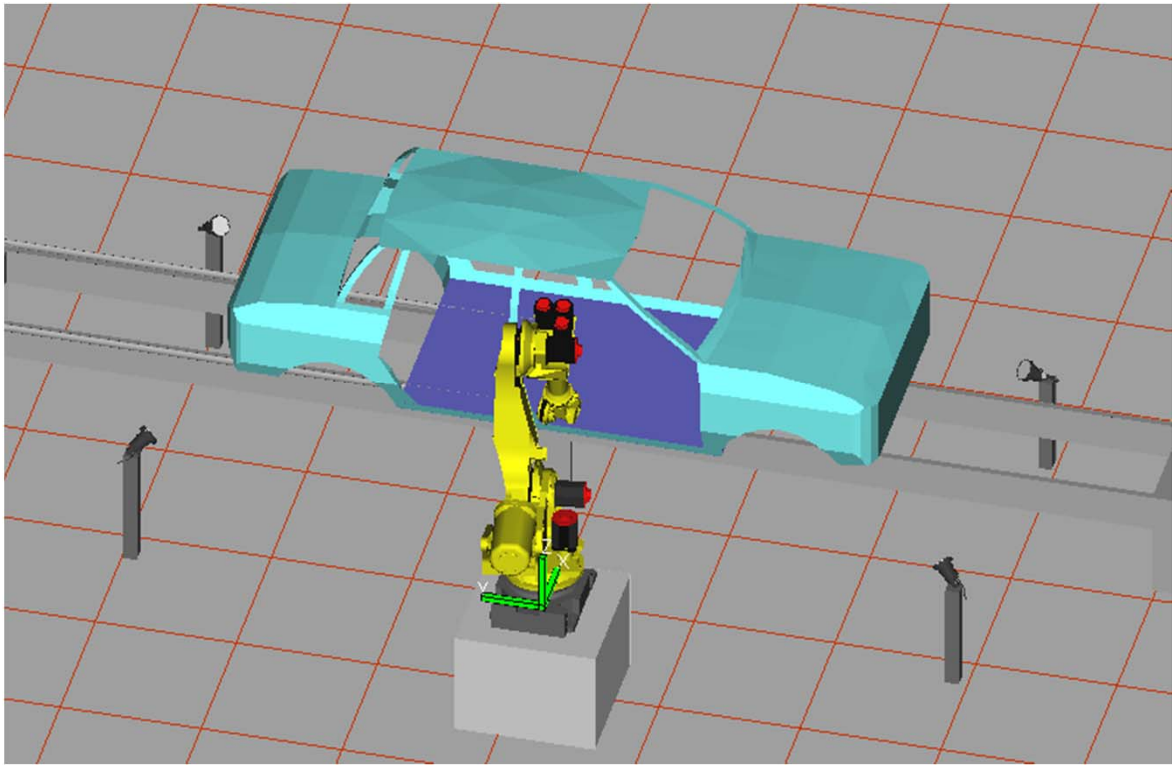


On round parts, transformations may not be applied to exactly the same point – creating the possibility of error.

Stereo Multiple View Example

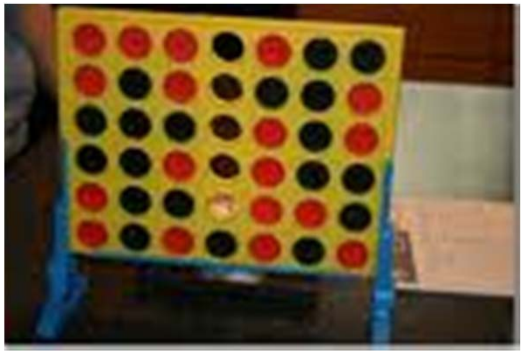
Locate the 3D position of a large rigid work surface or object

Requires a minimum of 3 positional views. 4th is used for improved fit calculations



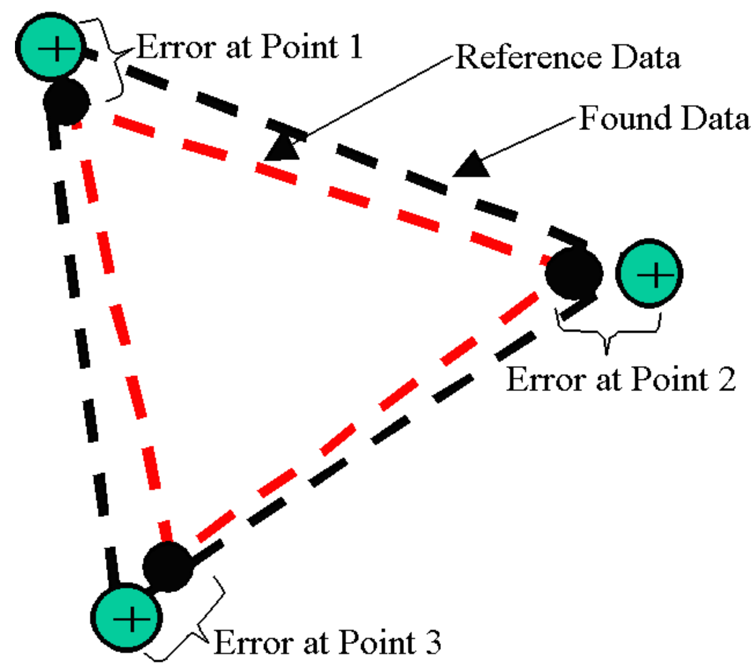
Applying Geometric Relationships

- Identify fixed and reliable geometric features (corners or holes)
- Apply Geometric Position Relationships between features
- Compensate for Perspective



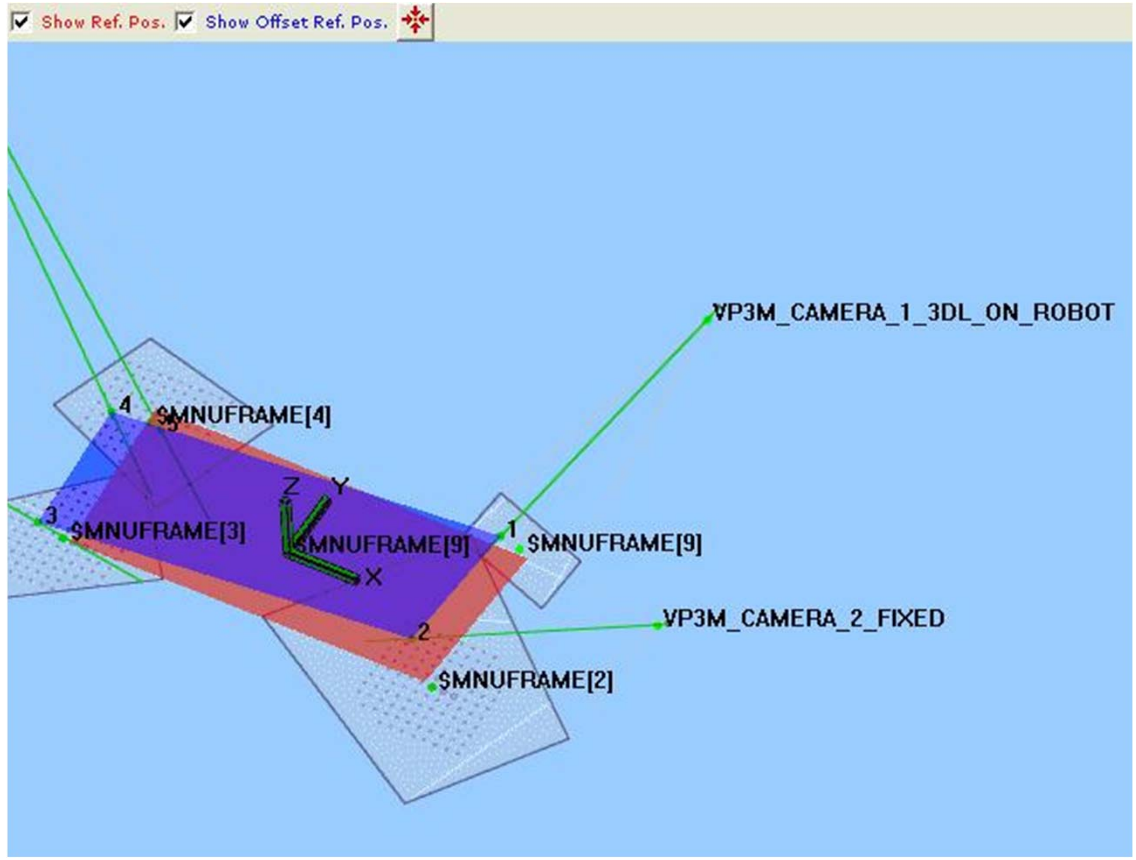
Geometric Relationships

- Start with a known shape
- Extract feature Point Position with respect to calibrated cameras
- The part shape is assumed to be constant although position is not
- Combine camera position relationship with found feature to extract new position



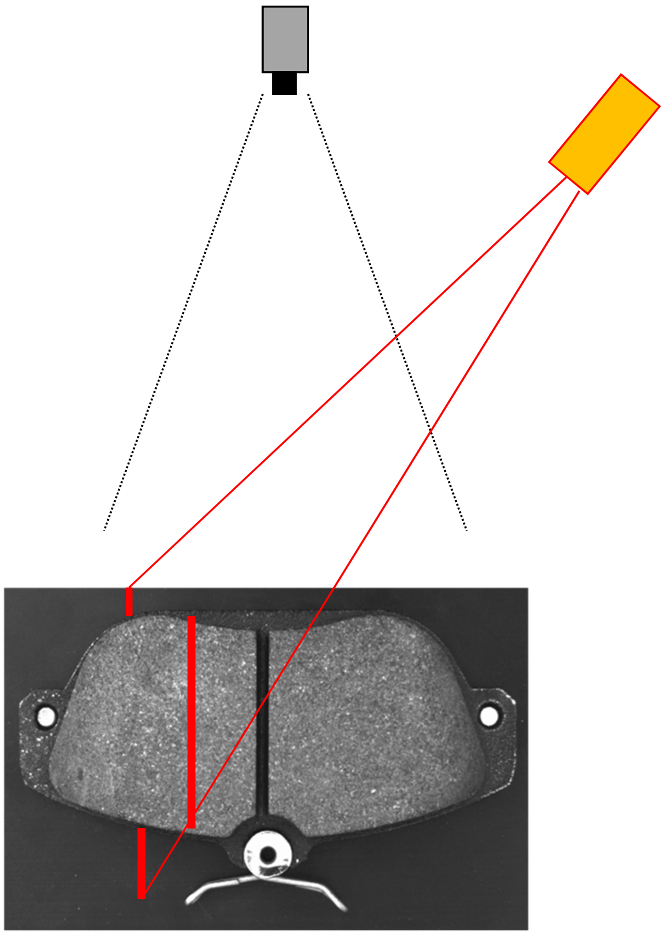
Planer Relationships

- Part setup requires assigning heights
- Using (4) 2D camera views pointing inward toward a large rigid body the 3 dimensional (3D) position can be determined



Triangulation Method for 3D Rendering

- Instead of comparing image data, this method uses light projected at an angle.
- The relationship of the light to the camera is known.
- Laser light provides high contrast
- Laser line projection provides surface relationship data



Bin Picking

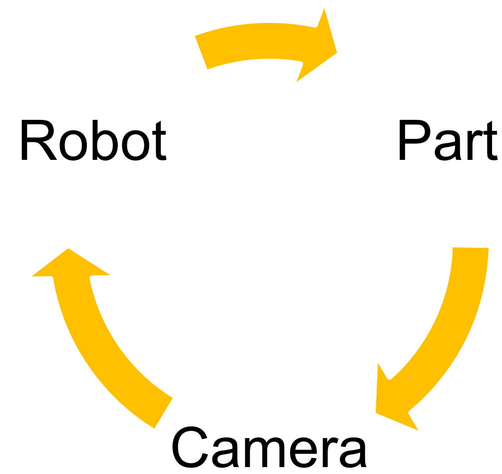
- Vision is used to:
  - Find the Bin
  - Find the part
  - Make sure not to collide with the bin walls
  - Pick the part with the robot tool at the right angle

3D Market

- Approximately 14% of ASMV systems sales are 3D
- 2D systems traditionally “X, Y and rotation”, whereas 3D systems provide “height, pitch and yaw”, too.
- 3D allows robots to place vacuum cups squarely on a flat surface, or pick a part so it is square to the tool
- Why not use 3D vision on all robot systems?
  - Cost.
  - Processing time.

Summary

- Robotic Vision is all about determining location
- Maintain Critical Relationships through calibration
  - Robot to Frame (Grid)
  - Frame to Camera
    - Orientation, direction and distance from the camera
  - Robot to Part
- How the part presents itself to the camera determines what type of vision is needed
  - 2D
  - 2.5D
  - 3D



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