# Vision-Guided Motion

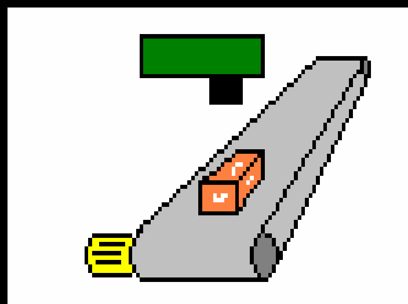
Presented by Tom Gray

# Overview

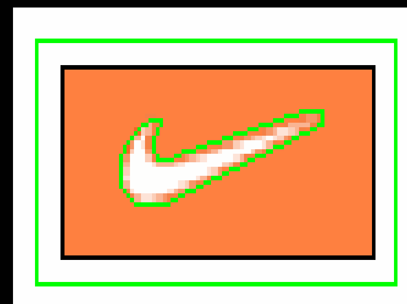
- Part I
  - Machine Vision Hardware
- Part II
  - Machine Vision Software
- Part II
  - Motion Control
- Part IV
  - Vision-Guided Motion – The Result

# Harley Davidson Example

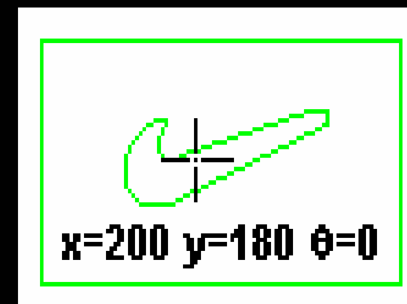
# Vision-Guided Motion Overview



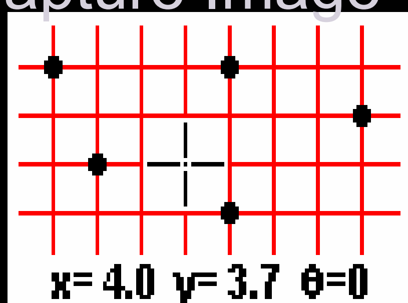
Capture Image



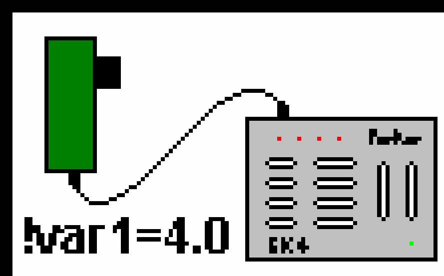
Locate Object



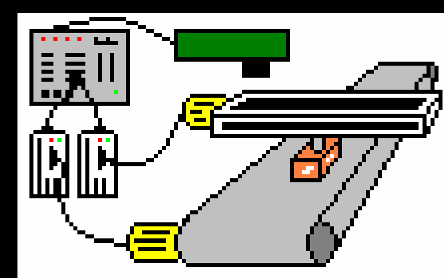

Determine XYΘ




Transform XYΘ




Send Data



Make Move

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# Part I – Machine Vision Hardware

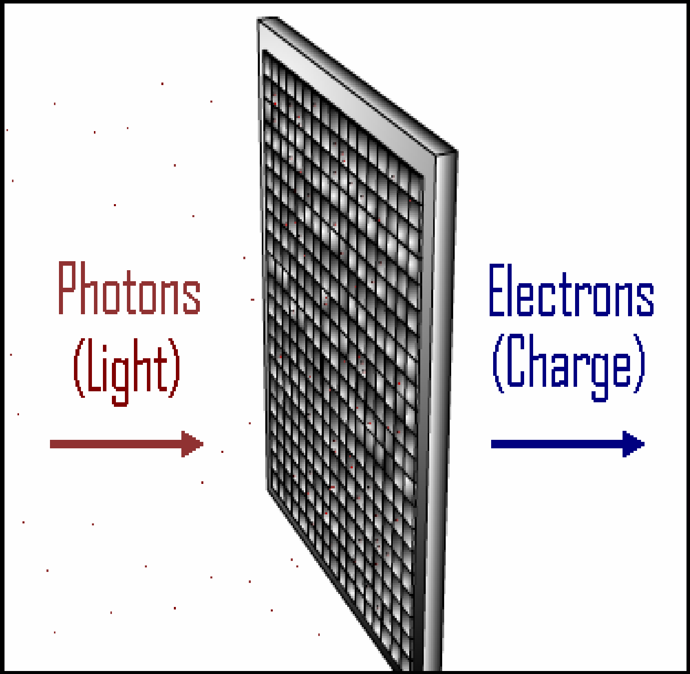
- Components of a SmartSensor
- How a CCD works
- Image Acquisition:
  - Environmental Protection
  - Triggers
  - Lighting
  - Lenses

# SmartSensor Components

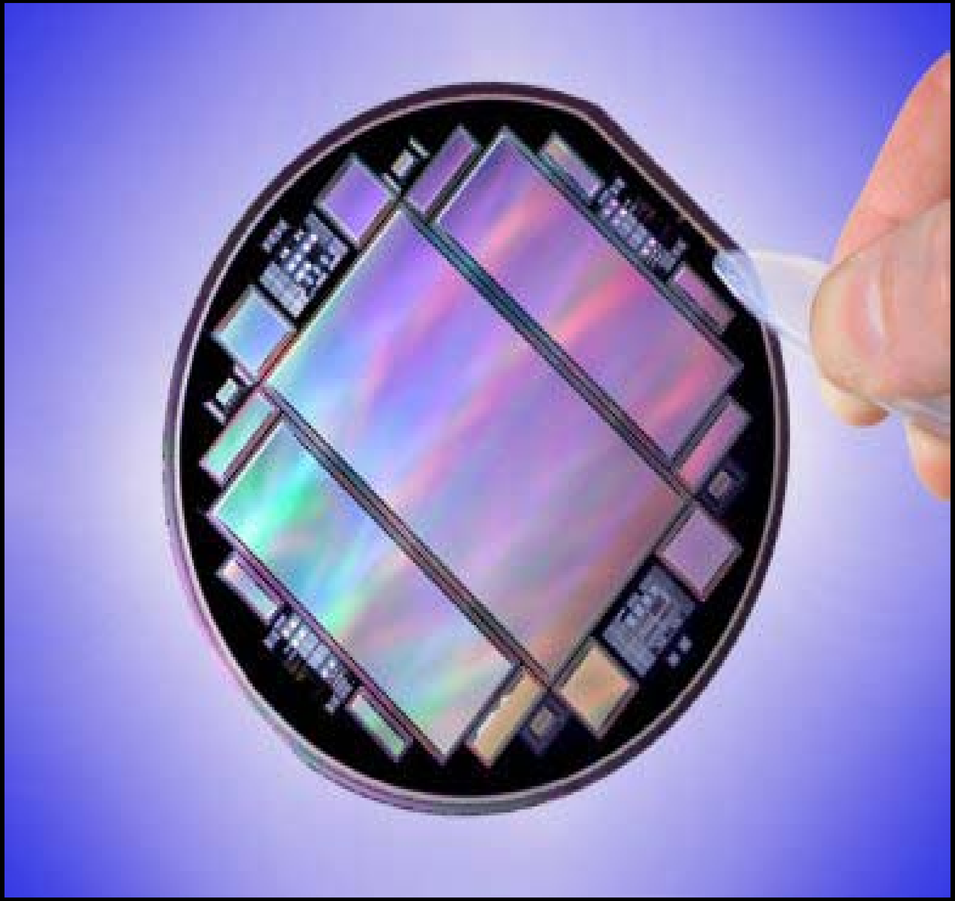
- CCD or CMOS for image capture
- RAM for memory storage
- FLASH for non-volatile storage
- Circuit Board for Components
- Image Processor
- Communications/IO Ports

# CCD Technology

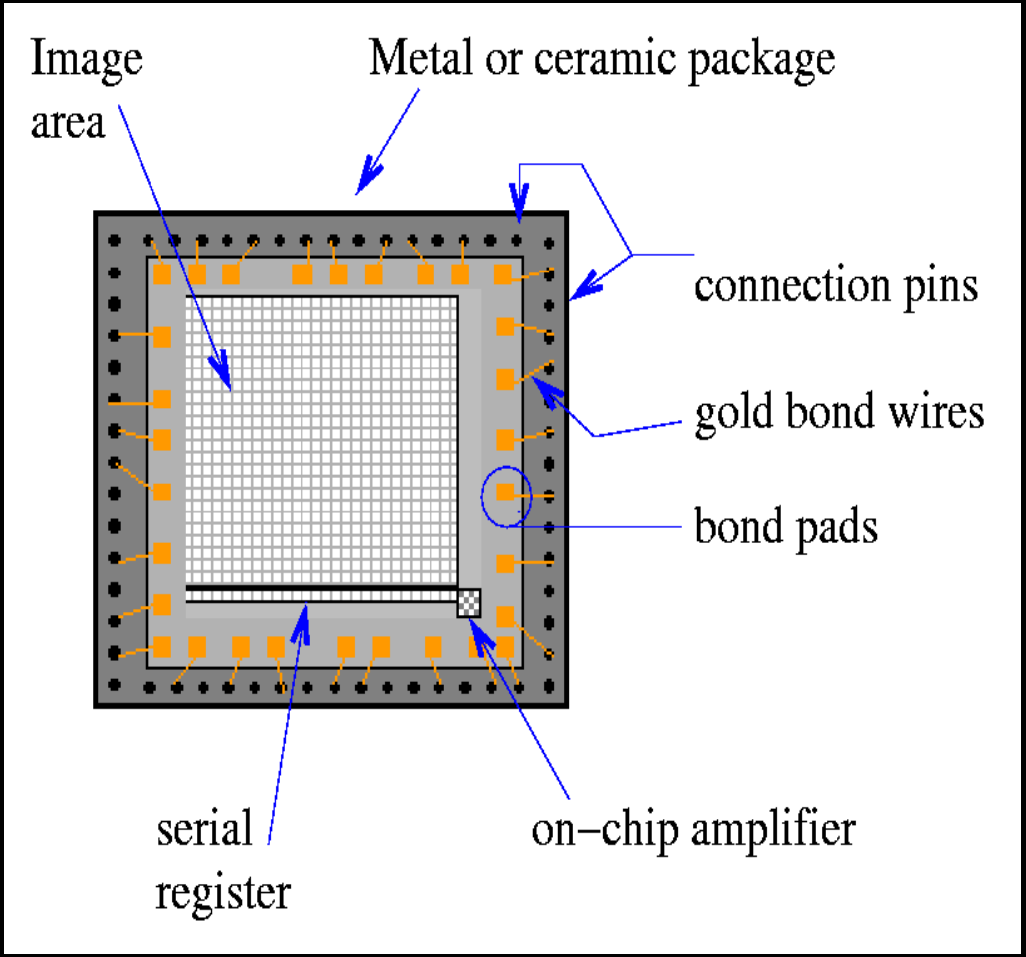
- CCD - Charged Coupled Device
- An array of diodes that turn Photons into Electrons
- More photons produce more electric charge



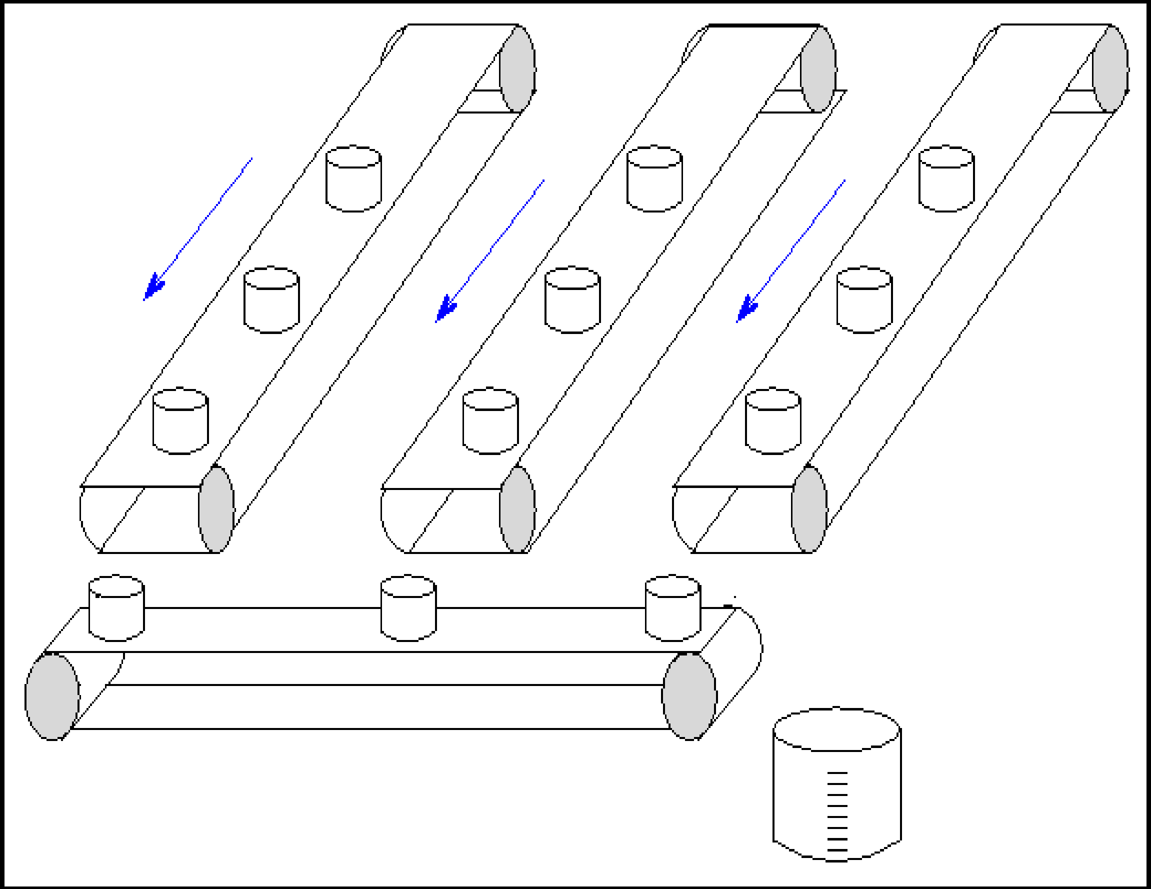
# CCD Manufacturing



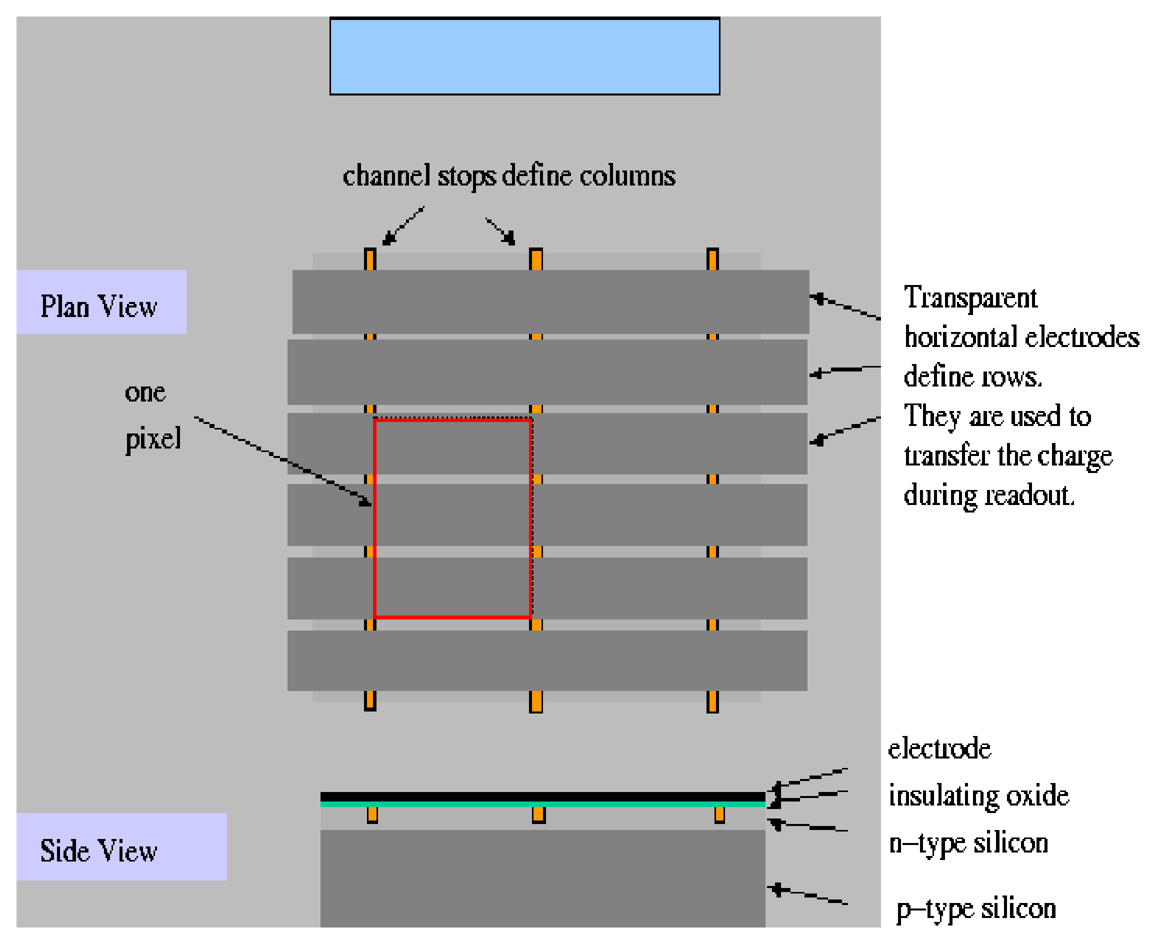
# CCD Structure



# CCD Conveyor Analogy

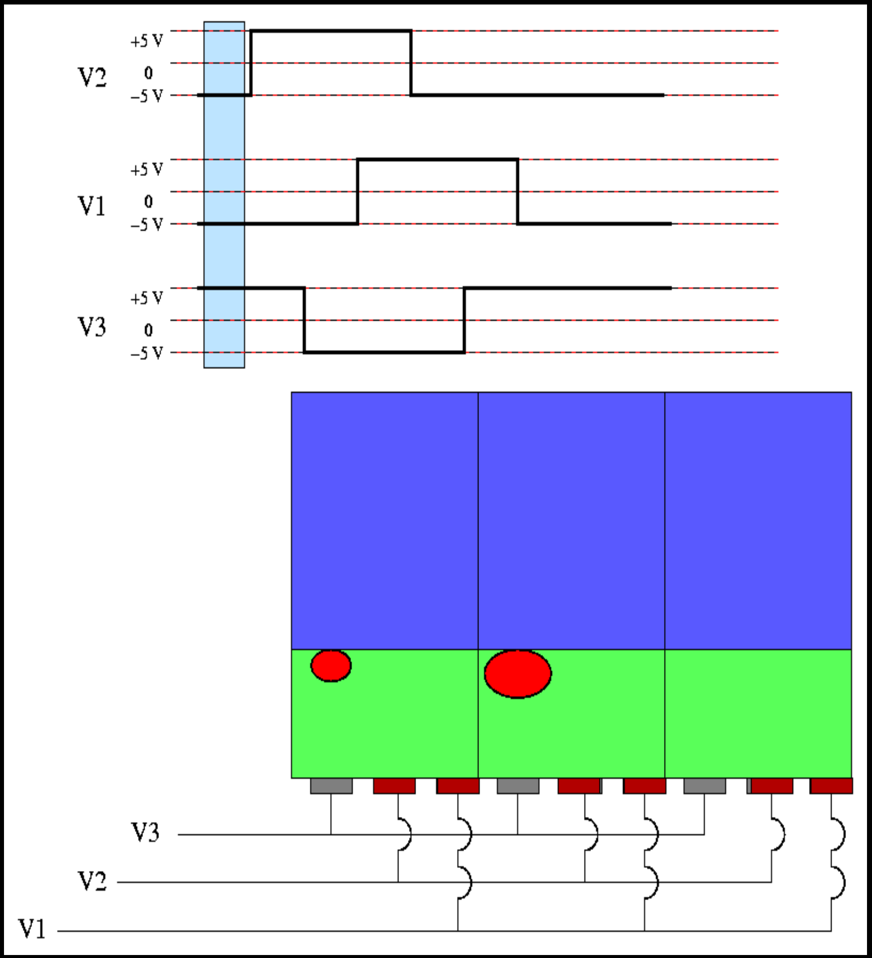


# CCD Layers



channel stops define columns
Plan View
one
pixel
Transparent horizontal electrodes define rows. They are used to transfer the charge during readout.
electrode
insulating oxide
n–type silicon
p–type silicon
Side View

# CCD Charge Shifting



# CCD vs. CMOS

- CMOS sensors connect standard transistors and wires to every pixel. Each pixel value is read independently
- CMOS sensors have lower light sensitivity
- CMOS sensors are slower and more susceptible to noise.
- CMOS sensor can be produced on standard silicon lines and are thus cost effective.

# CCD - Mixing Colored Light

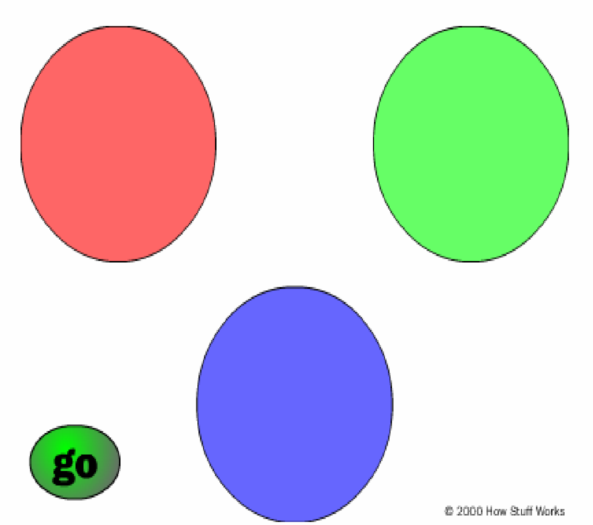



Figure 2. How the three colors mix to form many colors

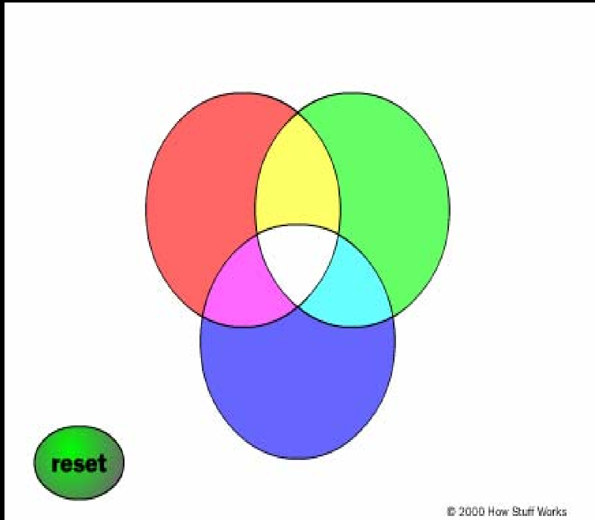
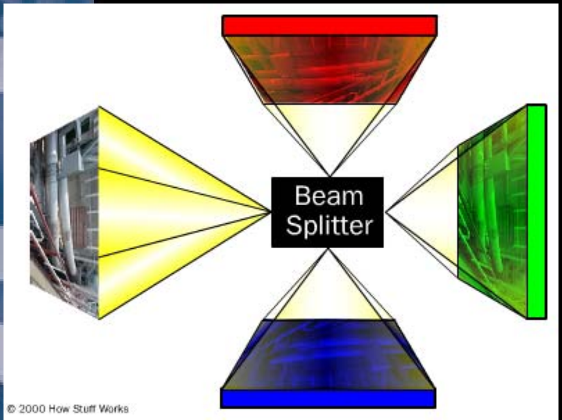


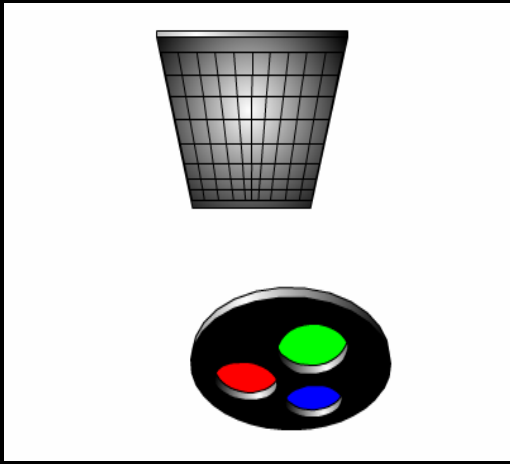

Figure 2. How the three colors mix to form many colors

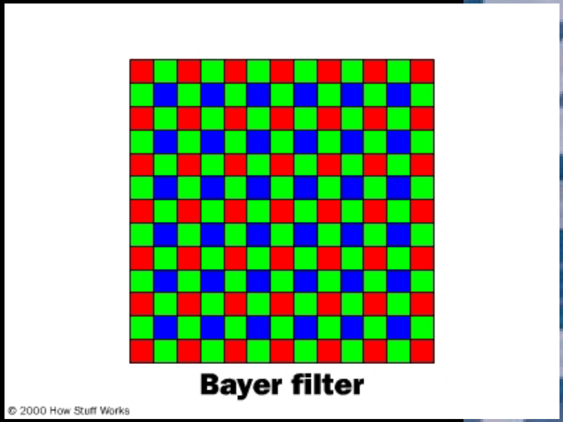
- Red, Green and Blue light combine to form every color in the spectrum.

# CCD - Capturing Color

- The light is filtered before it hits the CCD
- The most expensive systems use 3 CCDs
- A rotating filter can allow only one CCD
- A Bayer filter improves speed and cost





# Image Acquisition

- Environment
- Triggers
- Lighting
- Lenses

# Acquisition - Environment

- Controllable
  - Temperature
  - Wash-Down
- Maintainable
  - Grease
  - Dust
- Difficult
  - Smoke
  - Flying Debris

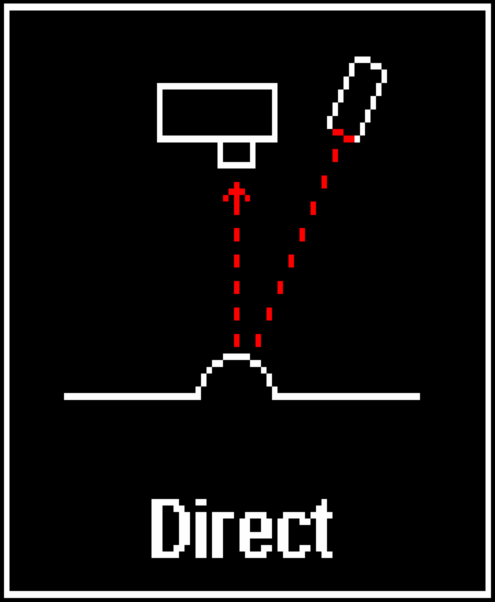
# Acquisition - Triggers

- Hardwired I/O
  - Almost every vision system requires a sensor to trigger the inspection
- Communications
  - Commands from Motion Controllers, PLCs and PCs can also trigger inspections

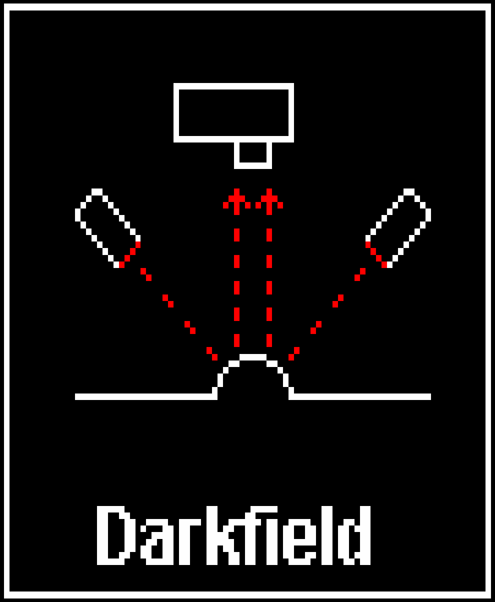
# Acquisition - Lighting

- The goal of lighting is to increase the contrast of the features you want to inspect
- Successful lighting involves a combination of up front design and experimentation
- Fortunately light generally travels in straight lines.

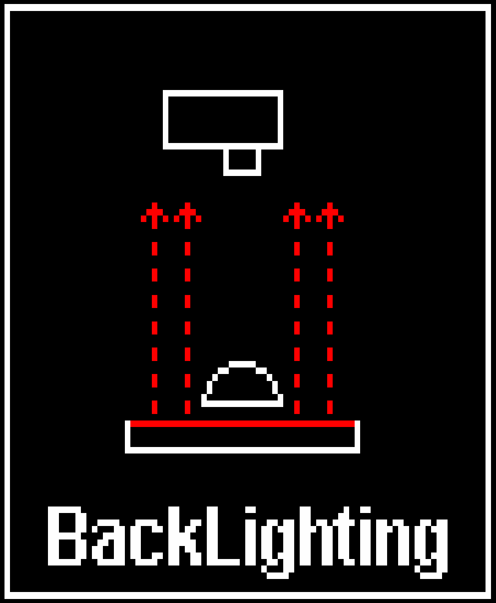
# Lighting - Direct



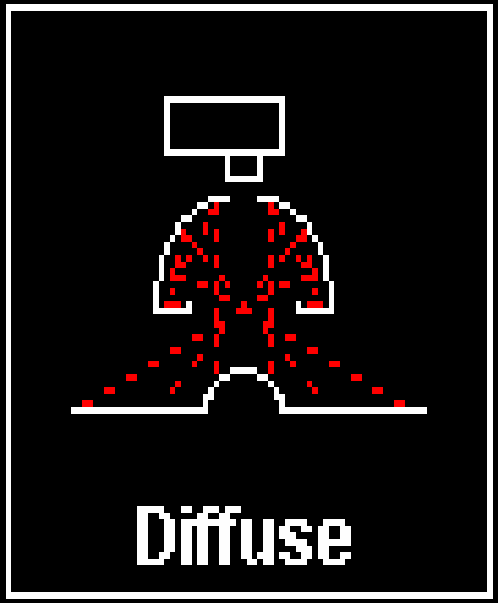
# Lighting - Darkfield



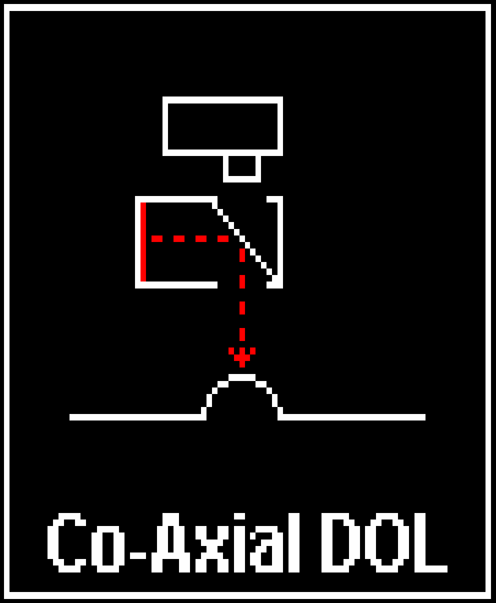
# Lighting - Backlit



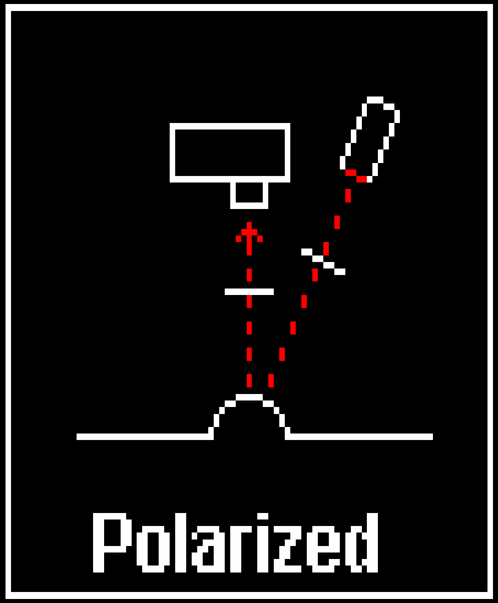
# Lighting - Diffuse



# Lighting – Co-Axial DOL



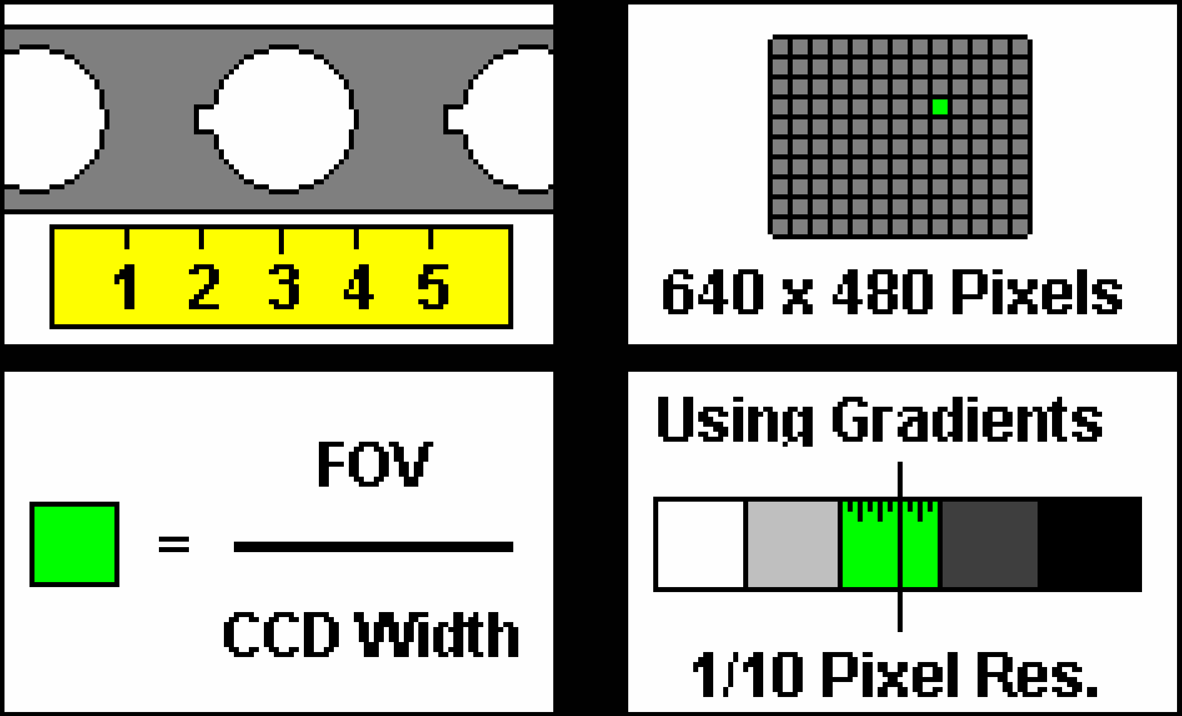
# Lighting – Polarized/Filtered



# Acquisition - Lenses

- Lenses selection is primarily driven by:
  - Field of View/Resolution
  - Object Distance
  - Depth of Focus
- Lens sizing charts help with field of view and object distance
- Telecentric, Aspherical or Zoom lenses add extra capability

# Calculating Resolution




2 in / 640 = .0031

OLYMPIC CONTROLS

# Series 600 Field of View Chart (in inches)

(All FOVs are approximate and are horizontal. To get vertical FOV multiply by 0.75.)

(Note, Extension Tube lengths (DVT PartNumber LNC-XKIT) are in paratheses where needed. This is in addition to the 5mm C/CS mount spacer)

| Lens | LNS-02FNO | LNS-04FNO | LNS-08FNO | LTC-16F | LTC-25F | LTC-50F | LTC-75F |
|---|---|---|---|---|---|---|---|
| **Focal Length** | **2.8 mm** | **4 mm** | **8 mm** | **16 mm** | **25 mm** | **50 mm** | **75 mm** |
| **Angle of View (H)** | 86.2 | 62 | 35.5 | 16.9 | 11 | 5.4 | 3.45 |
| **Min Obj Dist (in)** | Fixed | 11.7 | 11.7 | 11.8 | 9.8 | 11.7 | 19.7 |
| **Object Dist (in)** | | | | | | | |
| 4 | | | | ***1.3*** *(2mm)* | ***0.8*** *(5mm)* | ***0.1*** *(55mm)* | |
| 6 | ***11.2*** | ***7.2*** | ***3.8*** | ***1.8*** *(2mm)* | ***1.1*** *(2mm)* | ***0.4*** *(25mm)* | ***0.4*** |
| 8 | ***15.0*** | ***9.6*** | ***5.1*** | ***2.4*** *(1mm)* | ***1.5*** *(1mm)* | ***0.6*** *(15mm)* | ***0.5*** |
| 10 | ***18.7*** | ***12.0*** | ***6.4*** | ***3.0*** *(1mm)* | 1.9 | ***0.8*** *(5mm)* | ***0.6*** |
| 12 | 22.5 | 14.4 | 7.7 | 3.6 | 2.3 | ***1.0*** *(5mm)* | ***0.7*** |
| 14 | 26.2 | 16.8 | 9.0 | 4.2 | 2.7 | ***1.1*** *(3mm)* | ***0.8*** |
| 16 | 29.9 | 19.2 | 10.2 | 4.8 | 3.1 | ***1.4*** *(1mm)* | ***1.0*** |
| 18 | 33.7 | 21.6 | 11.5 | 5.3 | 3.5 | ***1.5*** *(0mm)* | ***1.1*** |
| 20 | 37.4 | 24.0 | 12.8 | 5.9 | 3.9 | 1.9 | 1.2 |
| 24 | 44.9 | 28.8 | 15.4 | 7.1 | 4.6 | 2.3 | 1.4 |
| 28 | 52.4 | 33.6 | 17.9 | 8.3 | 5.4 | 2.6 | 1.7 |
| 32 | 59.9 | 38.5 | 20.5 | 9.5 | 6.2 | 3.0 | 1.9 |
| 36 | 67.4 | 43.3 | 23.0 | 10.7 | 6.9 | 3.4 | 2.2 |
| 40 | 74.9 | 48.1 | 25.6 | 11.9 | 7.7 | 3.8 | 2.4 |
| 45 | 84.2 | 54.1 | 28.8 | 13.4 | 8.7 | 4.2 | 2.7 |
| 50 | 93.6 | 60.1 | 32.0 | 14.9 | 9.6 | 4.7 | 3.0 |

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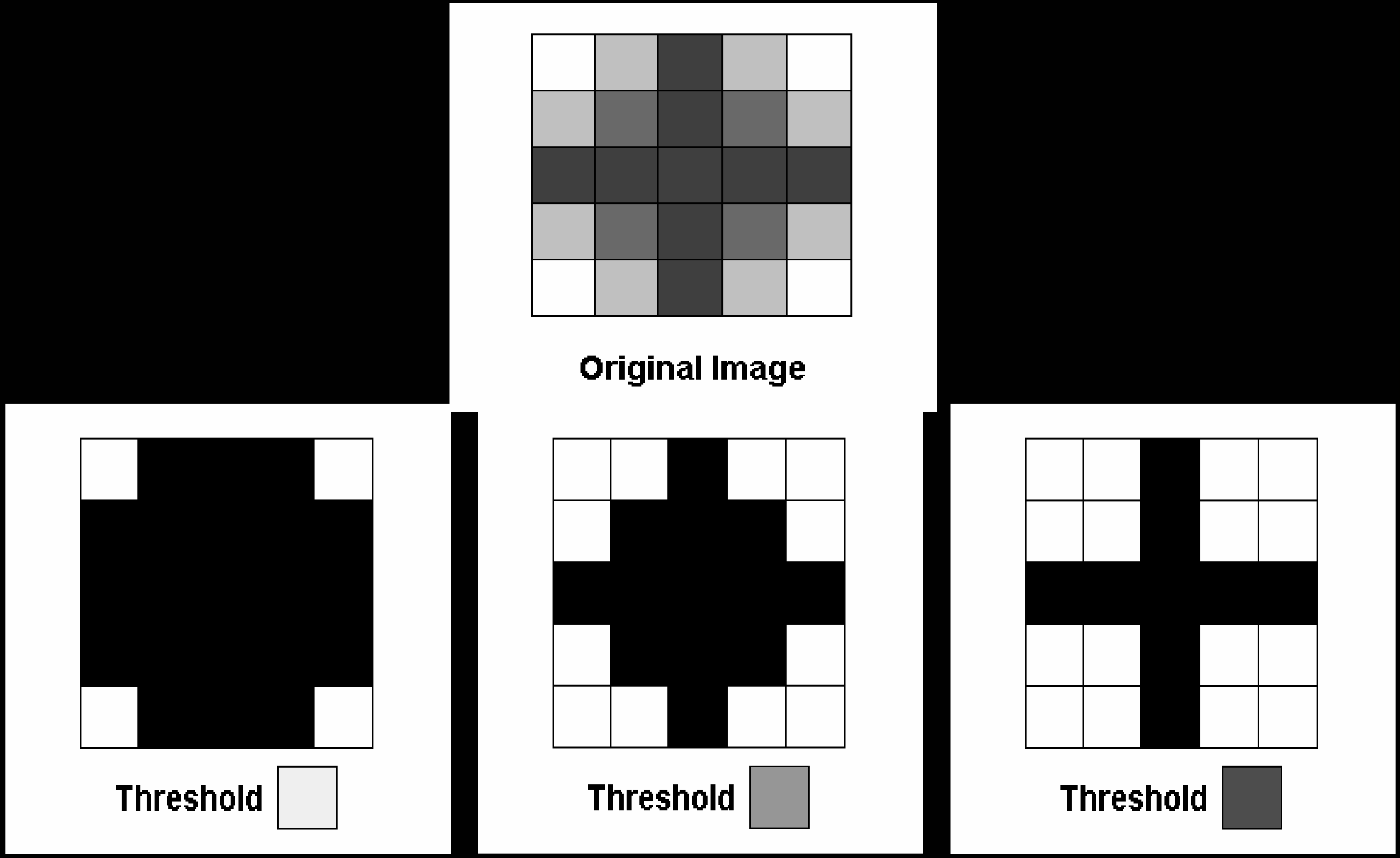
# Part II – Machine Vision Software

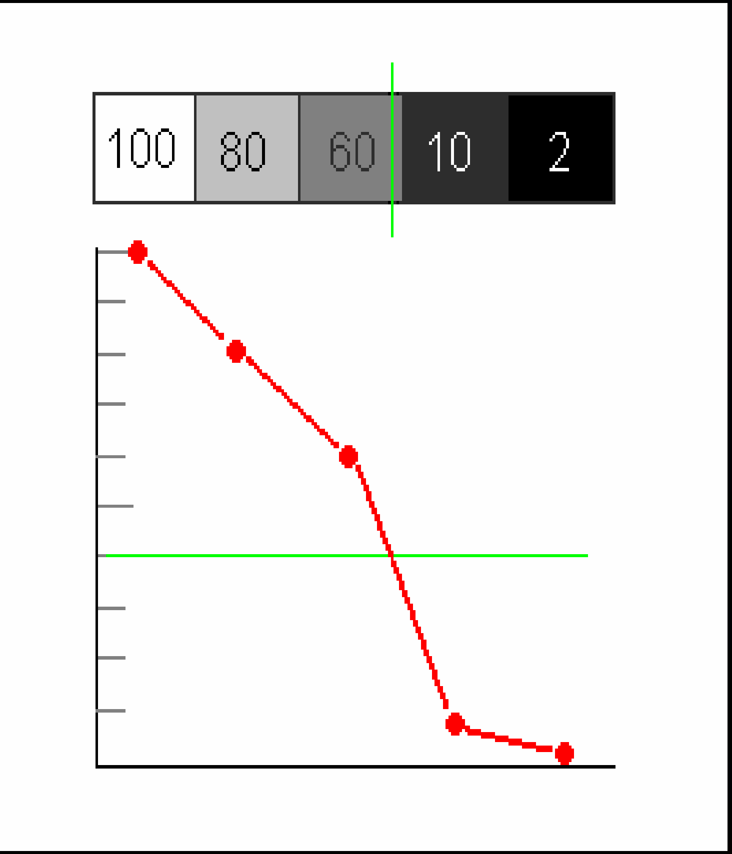
- Binary Thresholding
- Sub-pixel Values Intensity, Gradient, Centroid
- Image Processing Tools:
  - Intensity
  - Edge Finding
  - Precision Measurement
  - Blob Analysis
  - Object Location
  - Color Matching.

# Binary Thresholding



# Sub-Pixel Values - Intensity

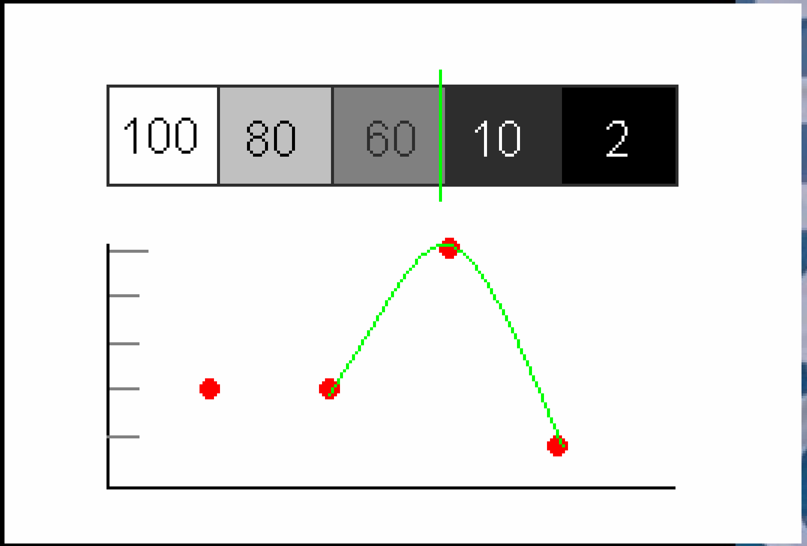
- Linear Interpolates to find an edge at an intensity level
- Adjusting the lighting can effect the edge value



# Sub-Pixel Values - Gradients

- Fit parabola to gradient values
- More resistant to small lighting changes

$$x = p + \frac{g_p - g_{p-1}}{2g_p - g_{p-1} - g_{p+1}}$$




X = Edge Location

p = Pixel Position

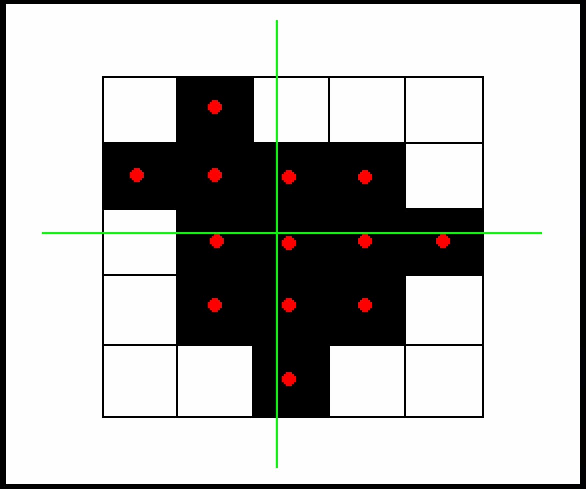
$g_p$ = Gradient between p and p+1

# Sub-Pixel Values - Centroid

- The center of an object can also be located to sub-pixel precision with a simple centroid calculation.
- 1/10 to 1/100 of a pixel can be achieved

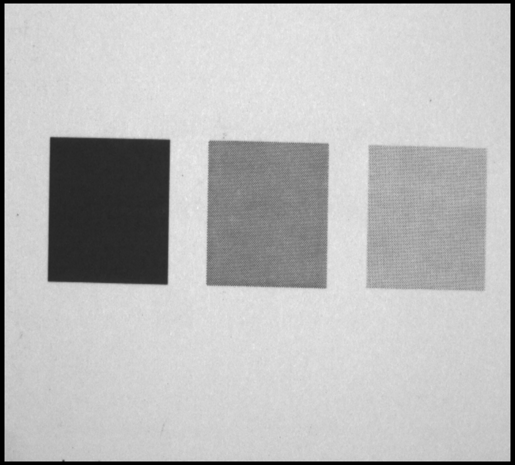
$$\bar{x} = \frac{1}{N_{pixels}} \sum_{N_{pixels}} x_{pixel}$$

$$\bar{y} = \frac{1}{N_{pixels}} \sum_{N_{pixels}} y_{pixel}$$



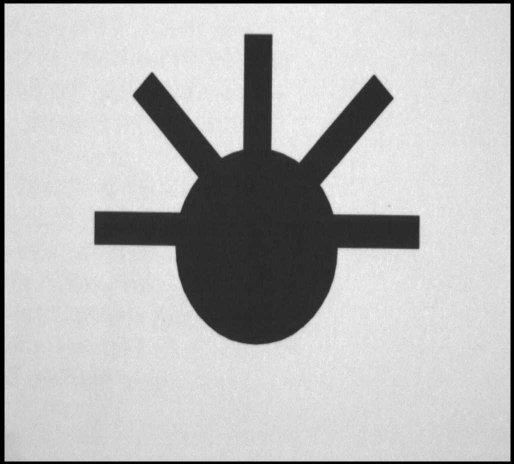
# Intensity

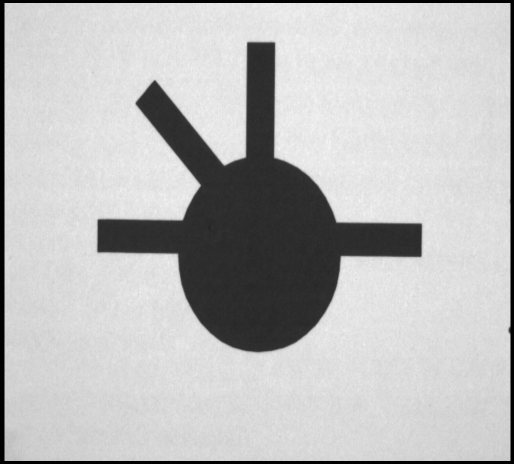
- Algorithm
  - Binary Threshold of pixels
  - Count the percent of light pixels
  - Compare with an acceptable value
- Applications
  - Determine if the lens cap is on
  - Determine that a coating has been applied



# Edge Finding/Counting

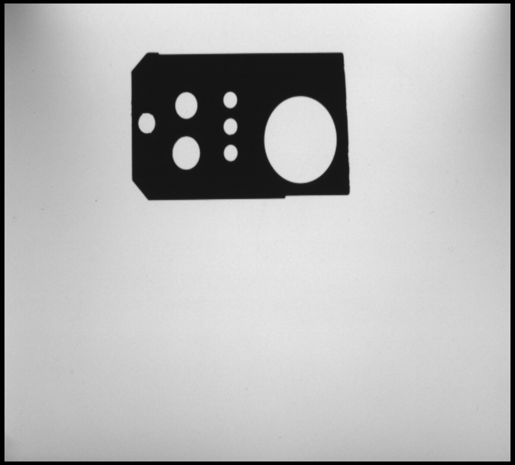
- Algorithm
  - Determine Pixel Values along a line
  - Count an edge each time the values cross the threshold
- Application
  - Connector Quality
  - Short-Shot Detection

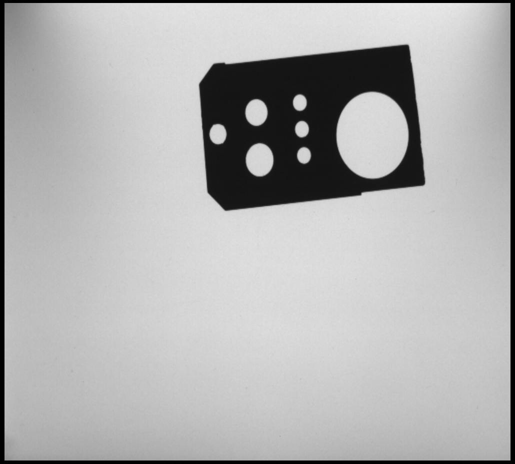




# Precision Measurement

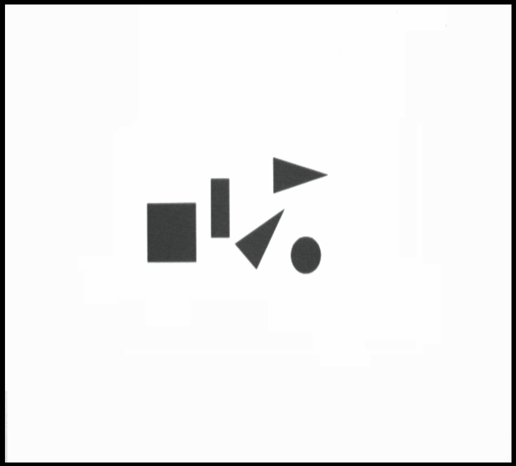
- Algorithm
  - Perform Edge Detection at multiple locations
  - Exclude outliers and average the values
- Application
  - Rivet hole location
  - Knife blade quality

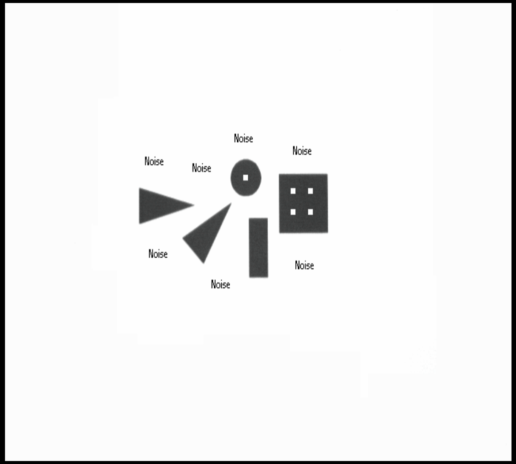




# Blob Analysis

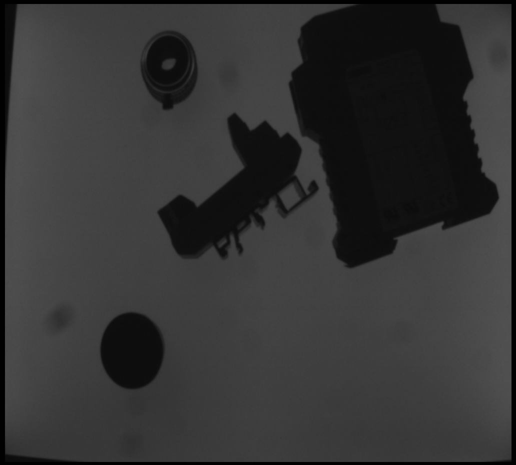
- Algorithm
  - Binary Threshold
  - Image Preprocessing
  - Group touching pixels
  - Filter and sort results
- Application
  - Candy Bar Sorting
  - Plywood Knot Check





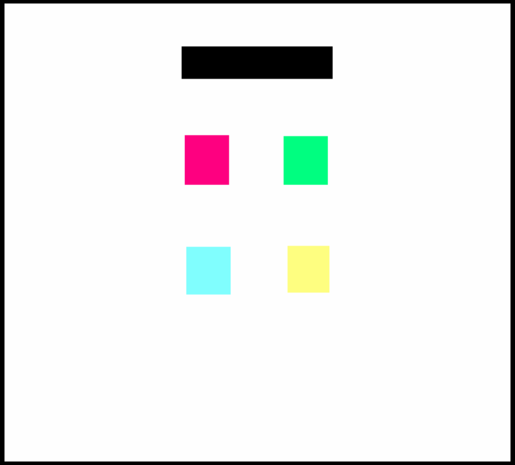
# Object Location

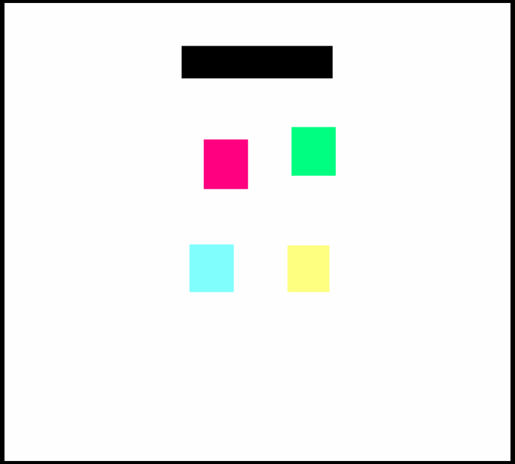
- Algorithm
  - Find Edge Points
  - Create Edge Segments
  - Compare with learned Segments
- Application
  - Pick and place robot
  - Label location



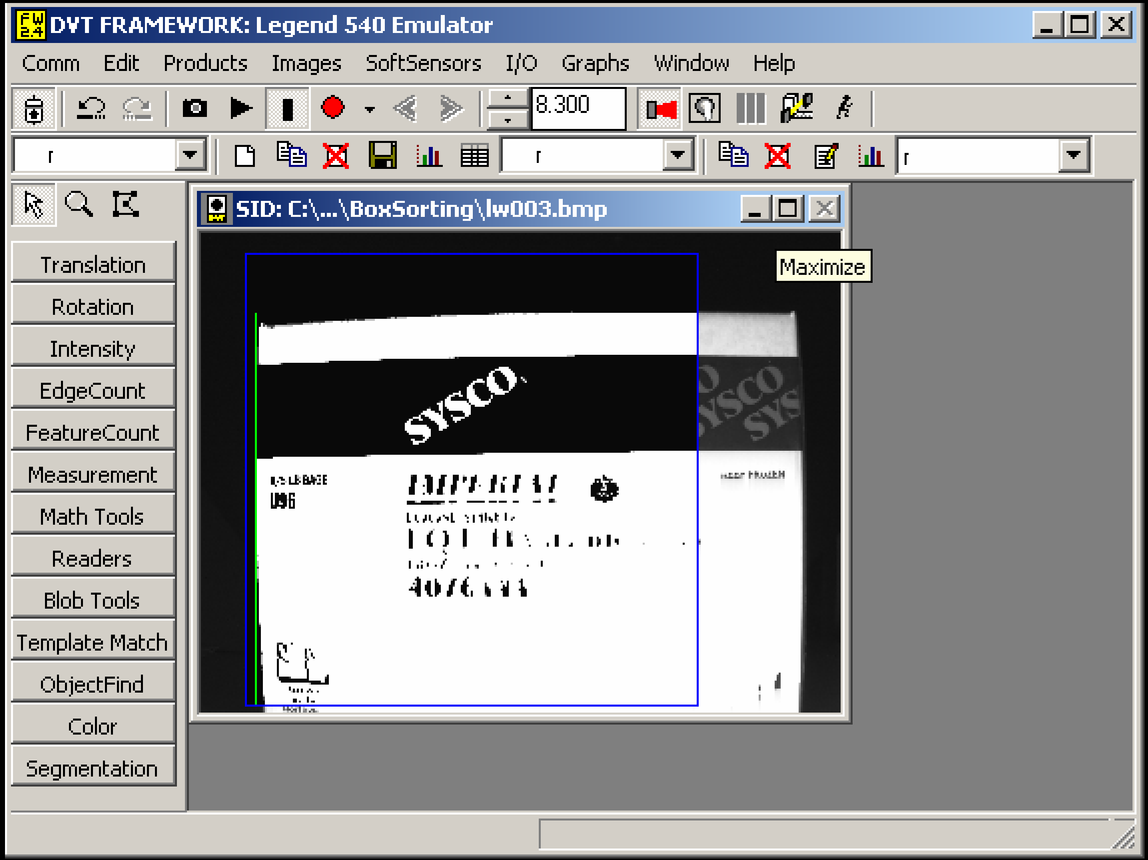
# Color Matching

- Algorithm
  - Teach multiple colors in RGB space
  - Detect an average color in an area
  - Compare with trained list
- Application
  - Print Registry
  - Gatorade Color Check





# Machine Vision Software Demo



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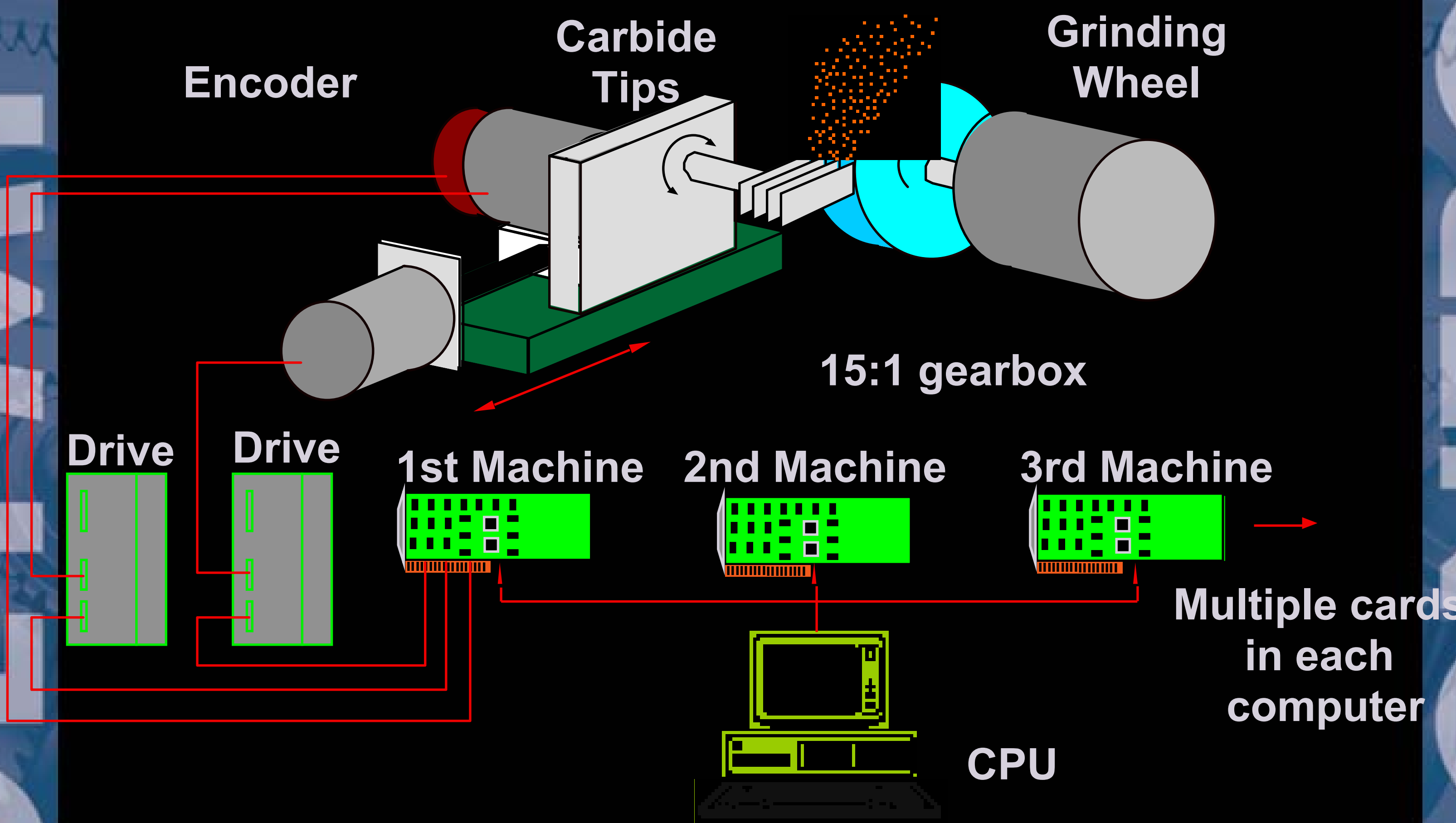
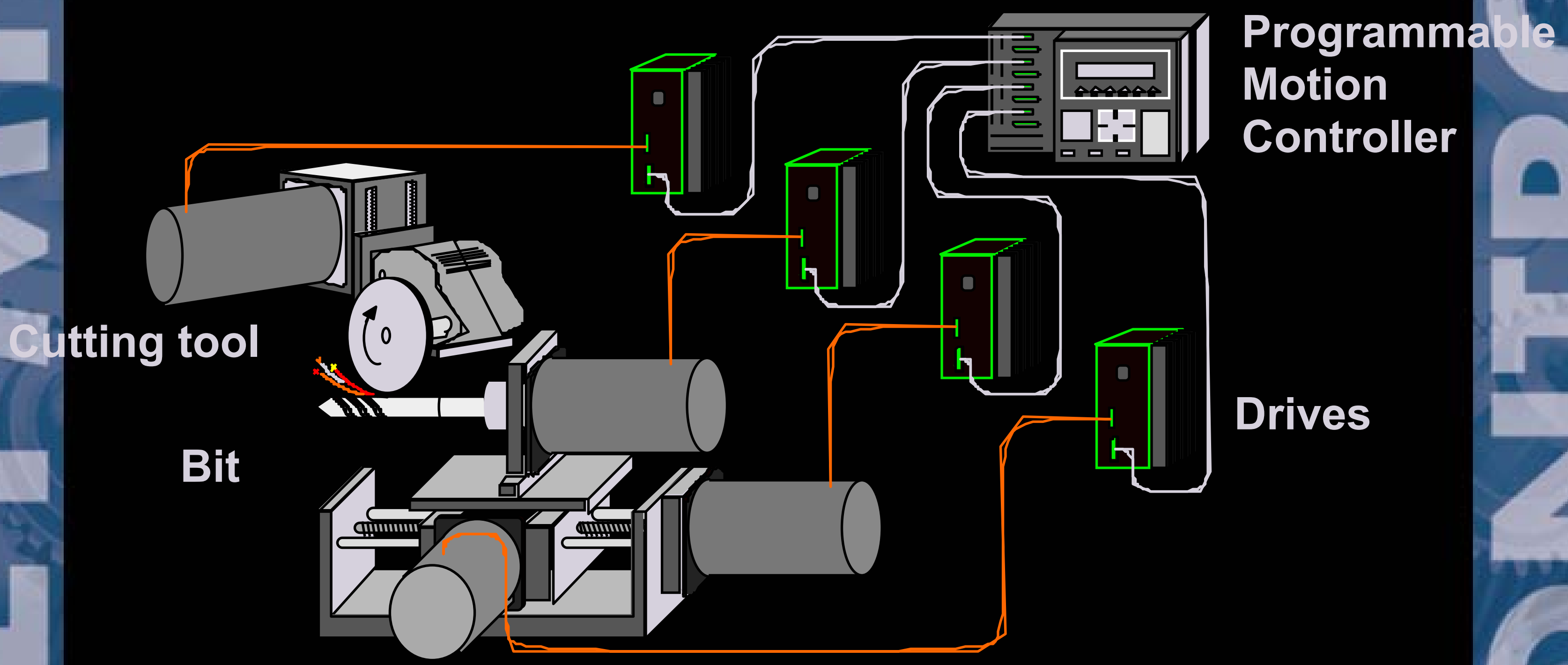
# Part III – Motion Control

- Architectures: Standalone, PC-based, Integrated
- Information Flow: Motion Controller, Drive/Amplifier, Motor, Mechanics.
- Feedback Loops: Torque, Velocity, Position, Application Level

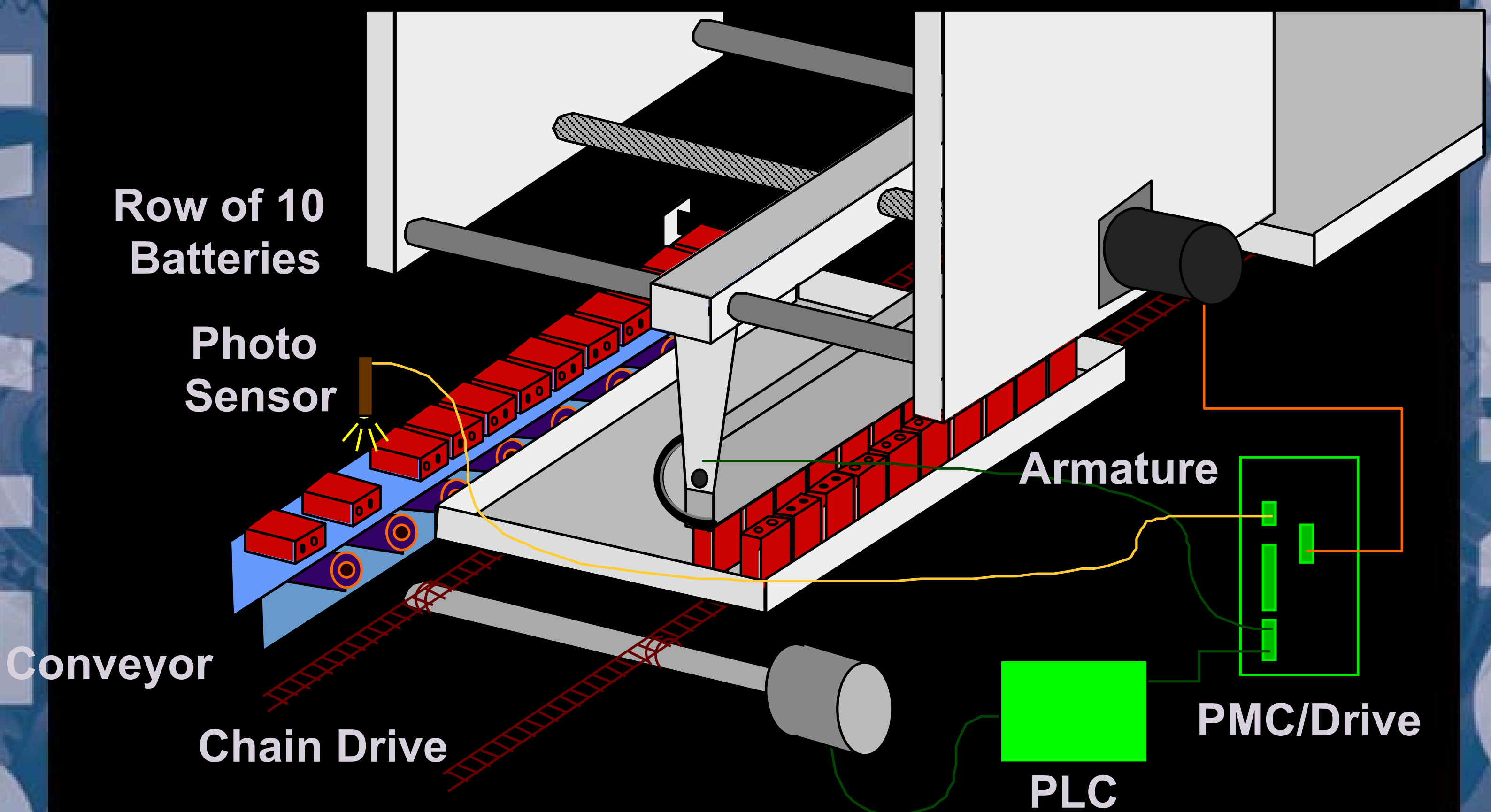
# Architecture - PC-Based



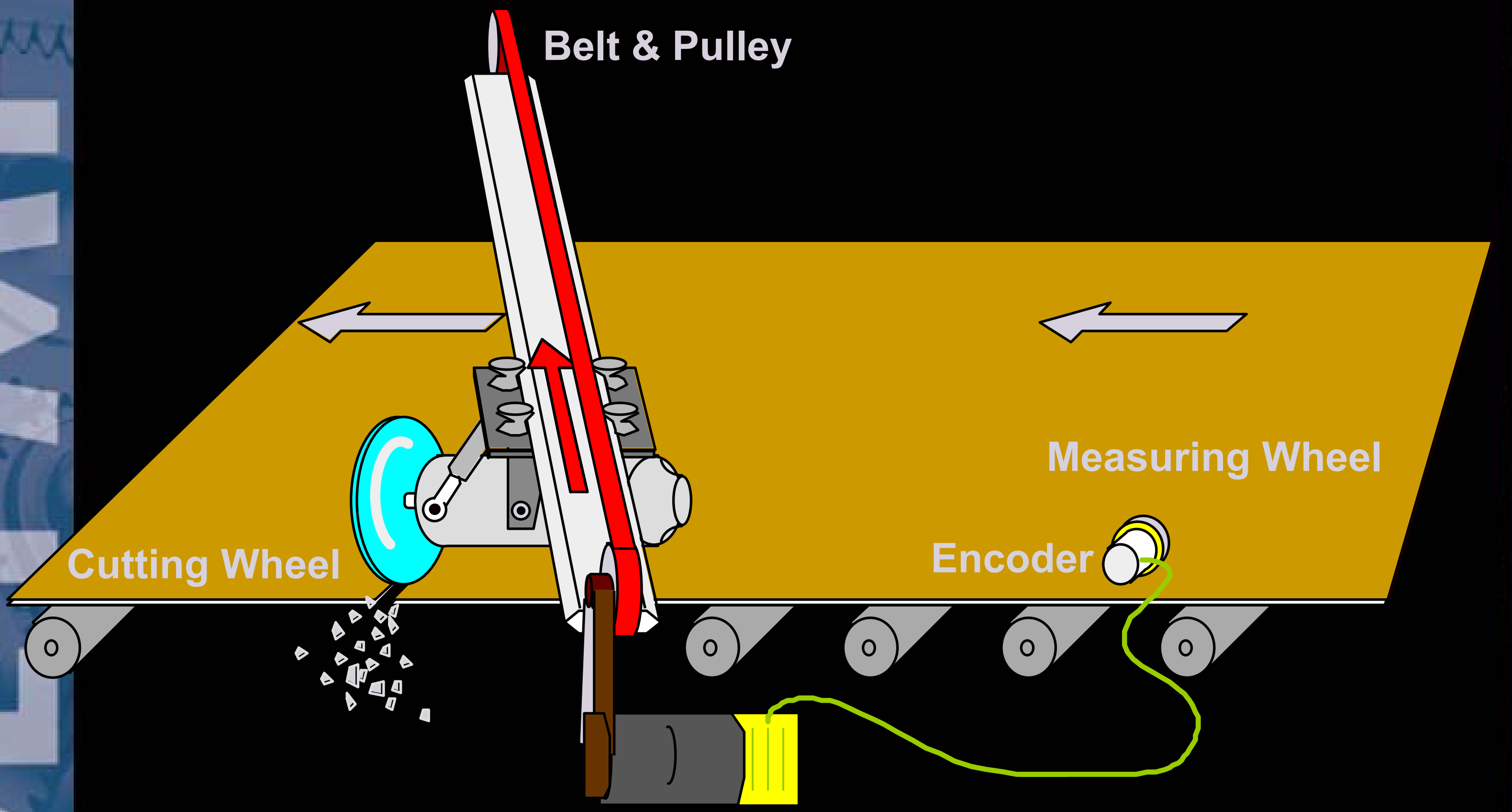
# Architecture - Stand Alone



# Architecture - PLC Based



# Architecture - Integrated



# Info Flow - Motion Controller

- Input
  - Stored Program Commands
  - Serial/Ethernet Commands
- Output
  - +/- 10 V signal (servo)
  - 5V TTL pulses (stepper)

# Info Flow - Drive/Amplifier

- Input
  - +/- 10 V signal
  - 5V TTL pulses
- Output
  - Commutated Current to motor windings

# Info Flow - Motor

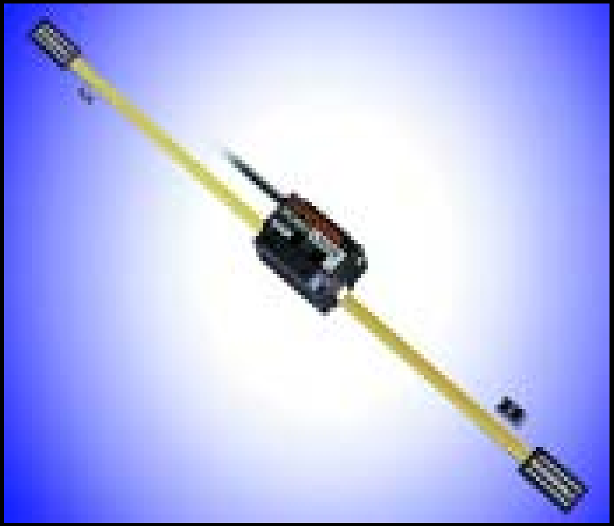
- Input
  - Commutated current to motor windings
- Output
  - Rotary or linear motion

# Info Flow - Mechanics

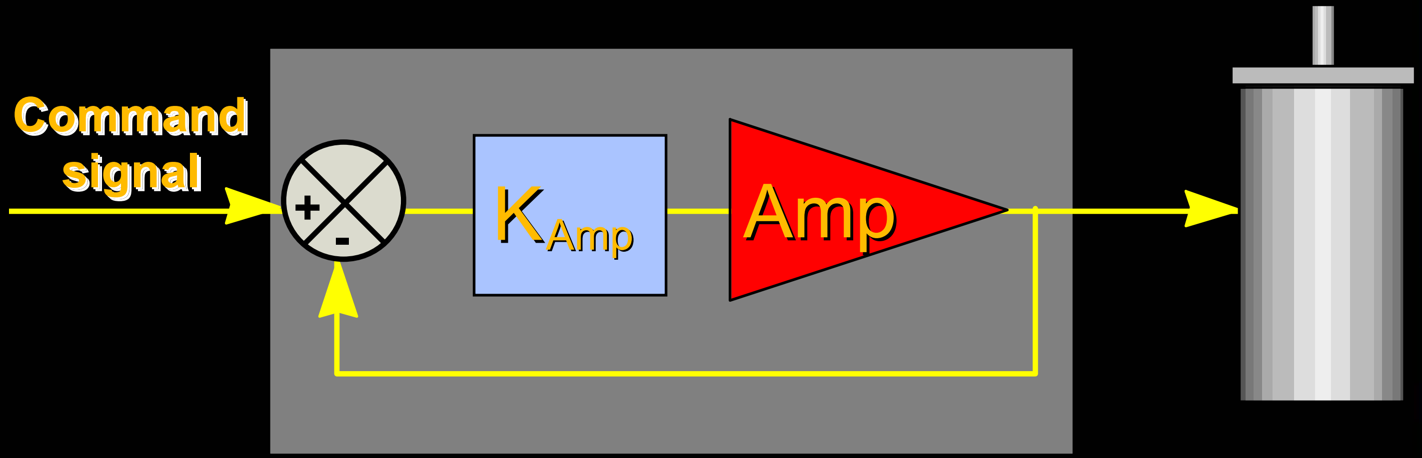
- Input
  - Rotary or Linear Motion from motor
- Output
  - Rotary or Linear Motion with mechanical advantage.

# Info Flow - Feedback Device

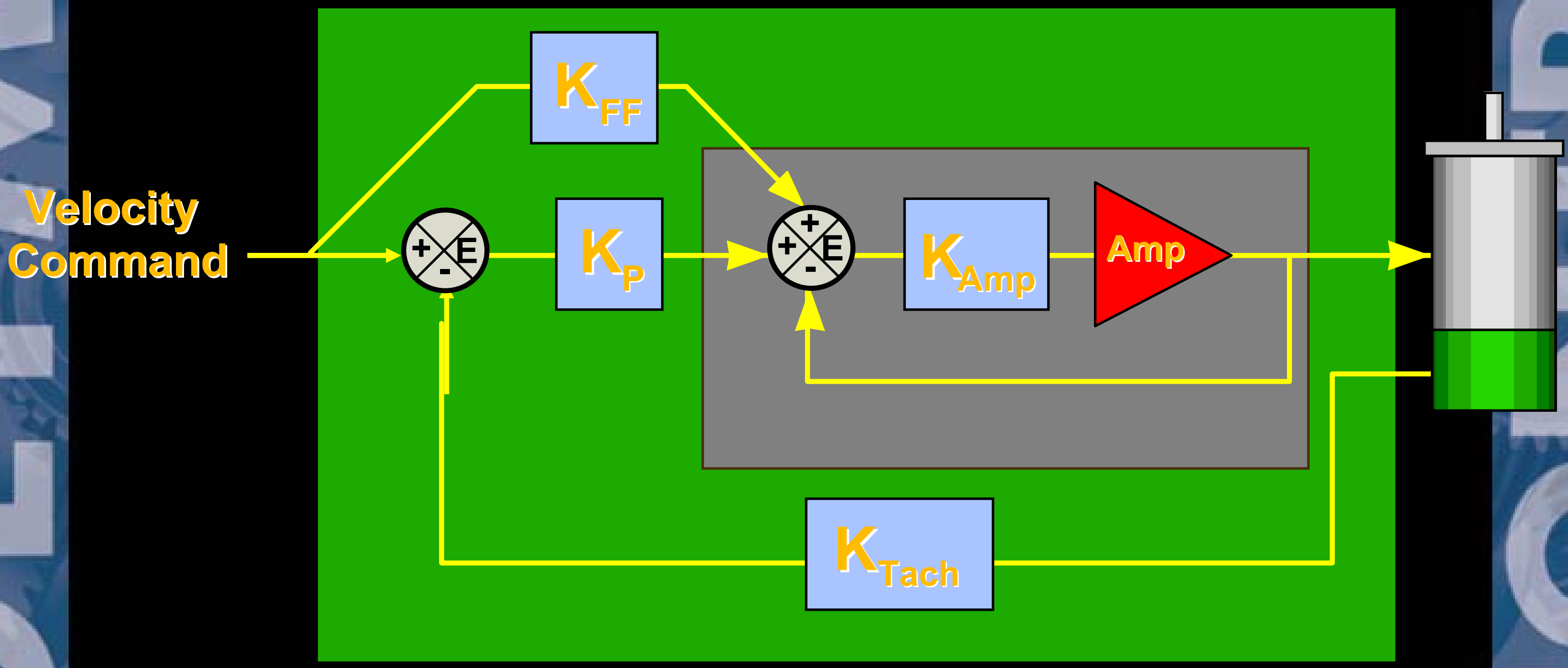
- Input
  - Encoder Pulses
  - Resolver Position
- Output
  - Quadrature signal
  - Analog Position Signal



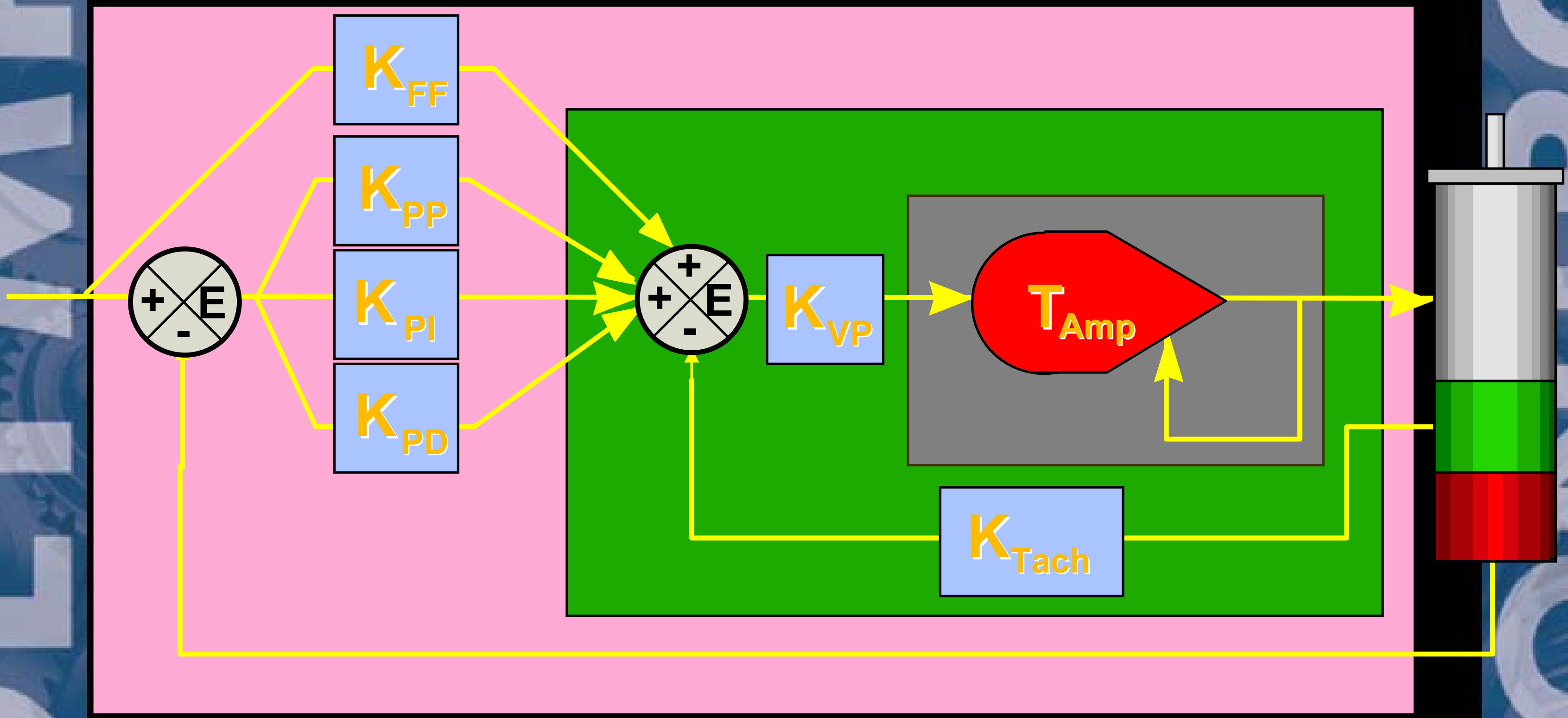
# Feedback - Torque Loop



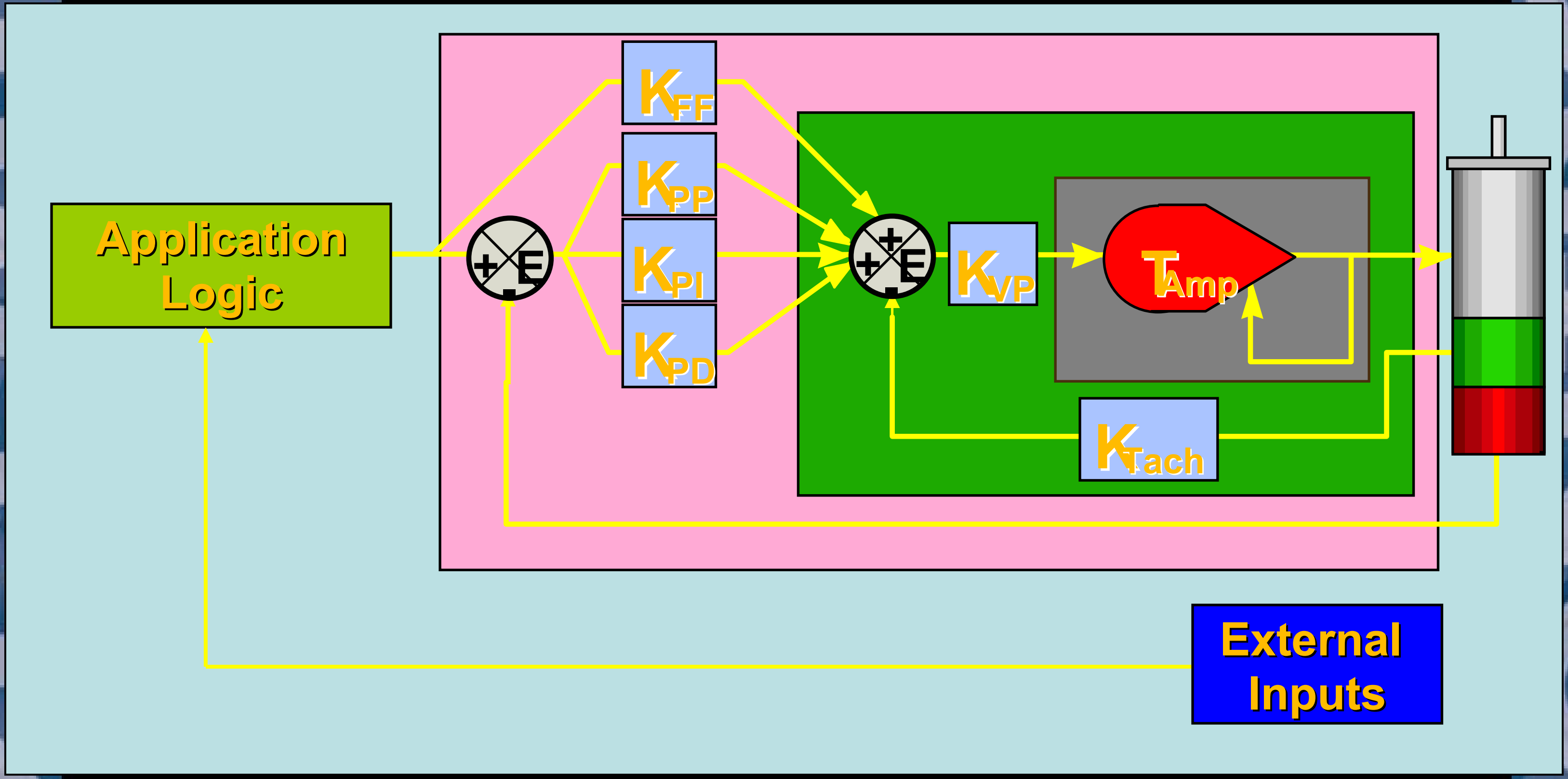
# Feedback - Velocity Loop



# Feedback - Position Loop



# Feedback - Application Logic



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# Part IV – Vision-Guided Motion

- Communications: Ethernet, Serial, Hardwired I/O
- Coordinate Transformations/Mapping
- Vision-Guided Motion Review
- Candy bar demonstration

# Communications

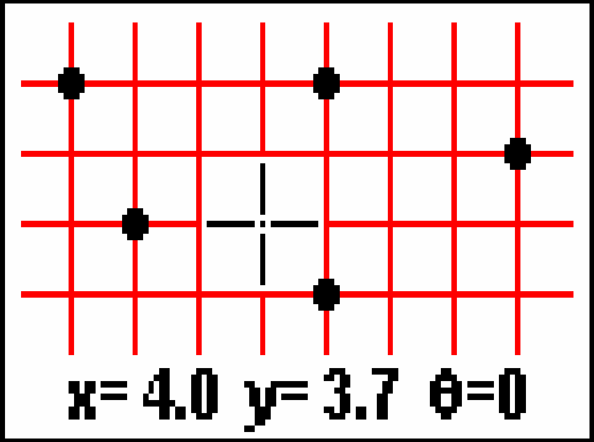
- The Vision Sensor must be able to send coordinates to the motion controller
- The Motion controller must be able to accept commands
- This means drivers

Ethernet

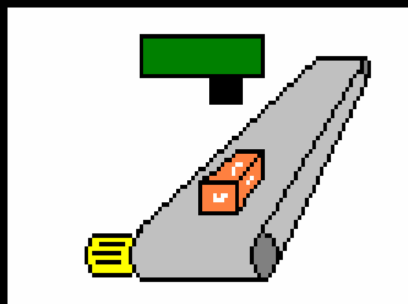
Serial I/O

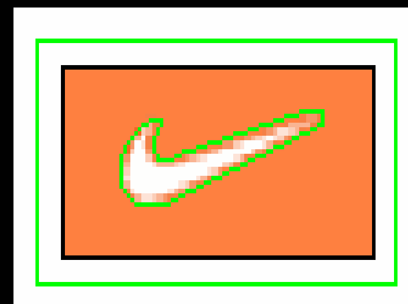
# Coordinate Transforms

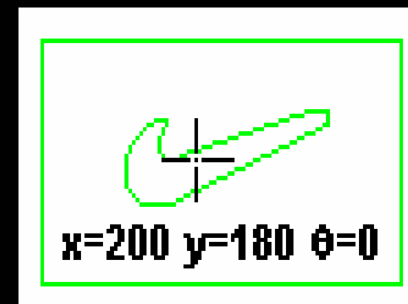
- The vision pixel coordinates must be converted to real world coordinates
- Done by:
  - Vision Sensor
  - Additional PC
  - Motion Controller



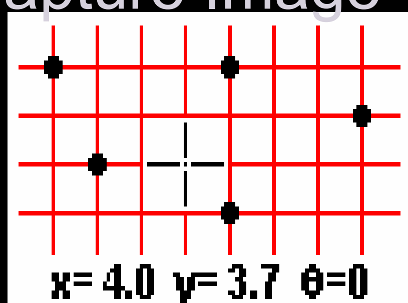
# Vision-Guided Motion Review

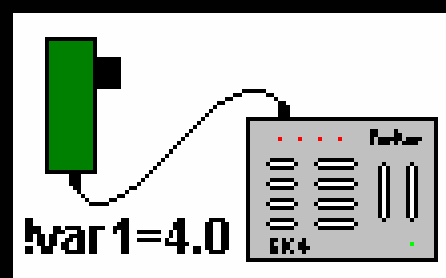


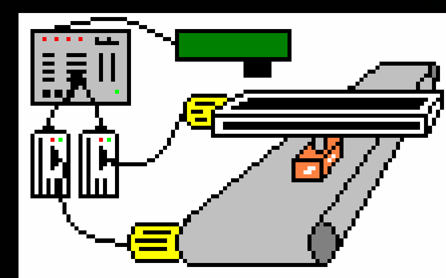





Capture Image Locate Object Determine XYΘ



Transform XYΘ Send Data Make Move

# Demonstration

# Thank You

http://www.howstuffworks.com

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