The Fundamentals of Machine Vision

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The Fundamentals of Machine Vision

INTRODUCTION AND OVERVIEW

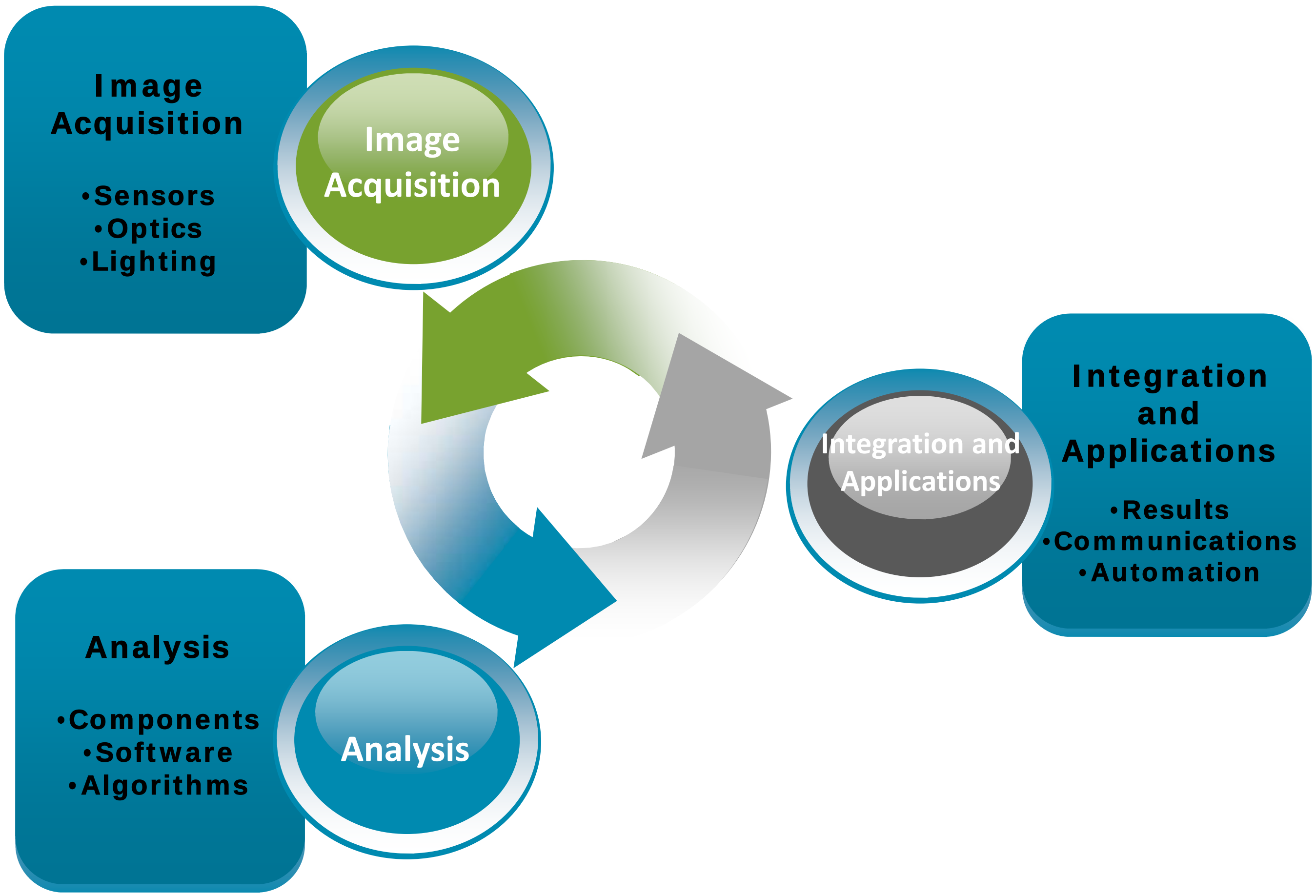
– What is Machine Vision
– The Machine Vision Market
– Industrial Uses of Machine Vision

Introduction and Overview

- What is Machine Vision
  - Machine vision is the substitution of the human visual sense and judgment capabilities with a video camera and computer to perform an inspection task. It is the automatic acquisition and analysis of images to obtain desired data for controlling or evaluating a specific part or activity.
  - Key Points:
    - Automated/Non-Contact
    - Acquisition
    - Analysis
    - Data

Introduction and Overview

- What is Machine Vision

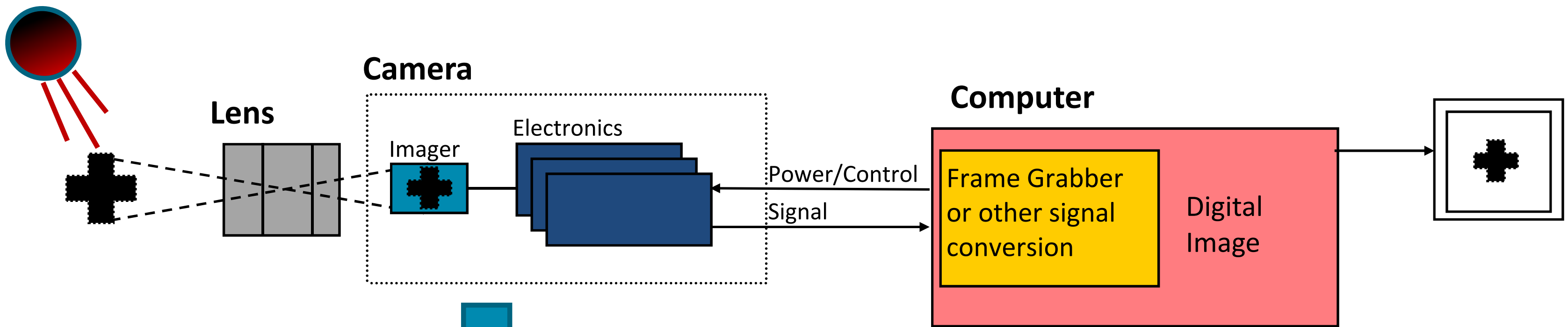


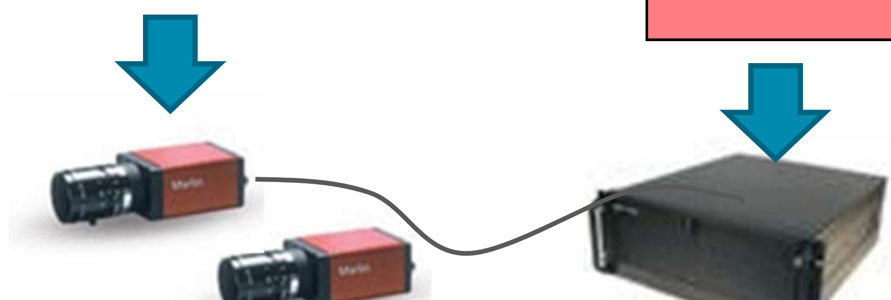
Introduction and Overview

- The Machine Vision Market
  - Choices
    - Well over 400 manufacturers and suppliers
    - Diverse product offerings
  - Confusion
    - Product/component differentiation sometimes is unclear
    - End-users (the buyers) often don’t understand what they are getting
  - What’s important
    - Components and techniques need to be better understood at the end-user level
    - Advanced technology skills are necessary for competent specification and integration

Introduction and Overview

- The Machine Vision Market
  - General Purpose Machine Vision Systems

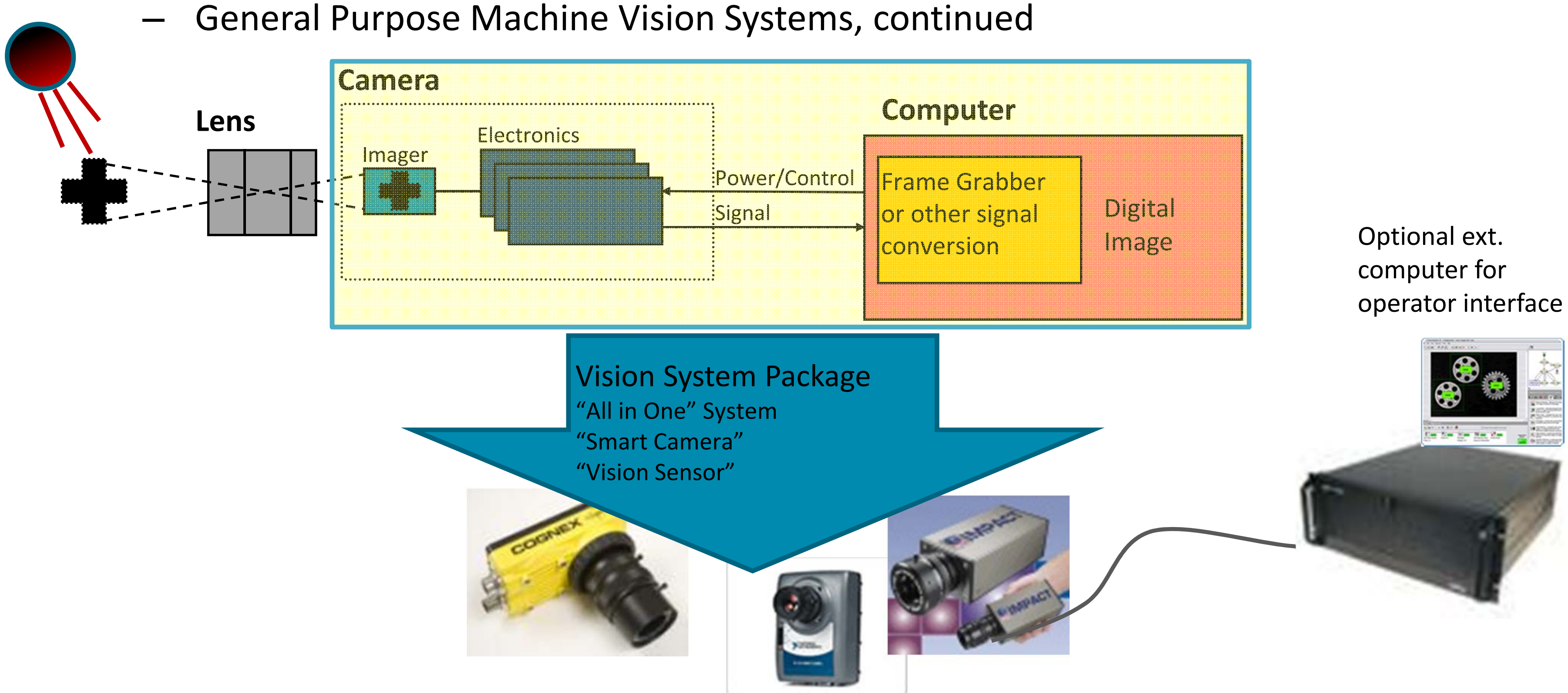




  - PC-based system
  - Single or multiple cameras interfaced to a computer, standard (Windows, Linux) operating system
  - Diverse imaging devices available
    - analog (RS170), and digital (GigE Vision, FireWire, Camera Link, USB) interfaces

Introduction and Overview

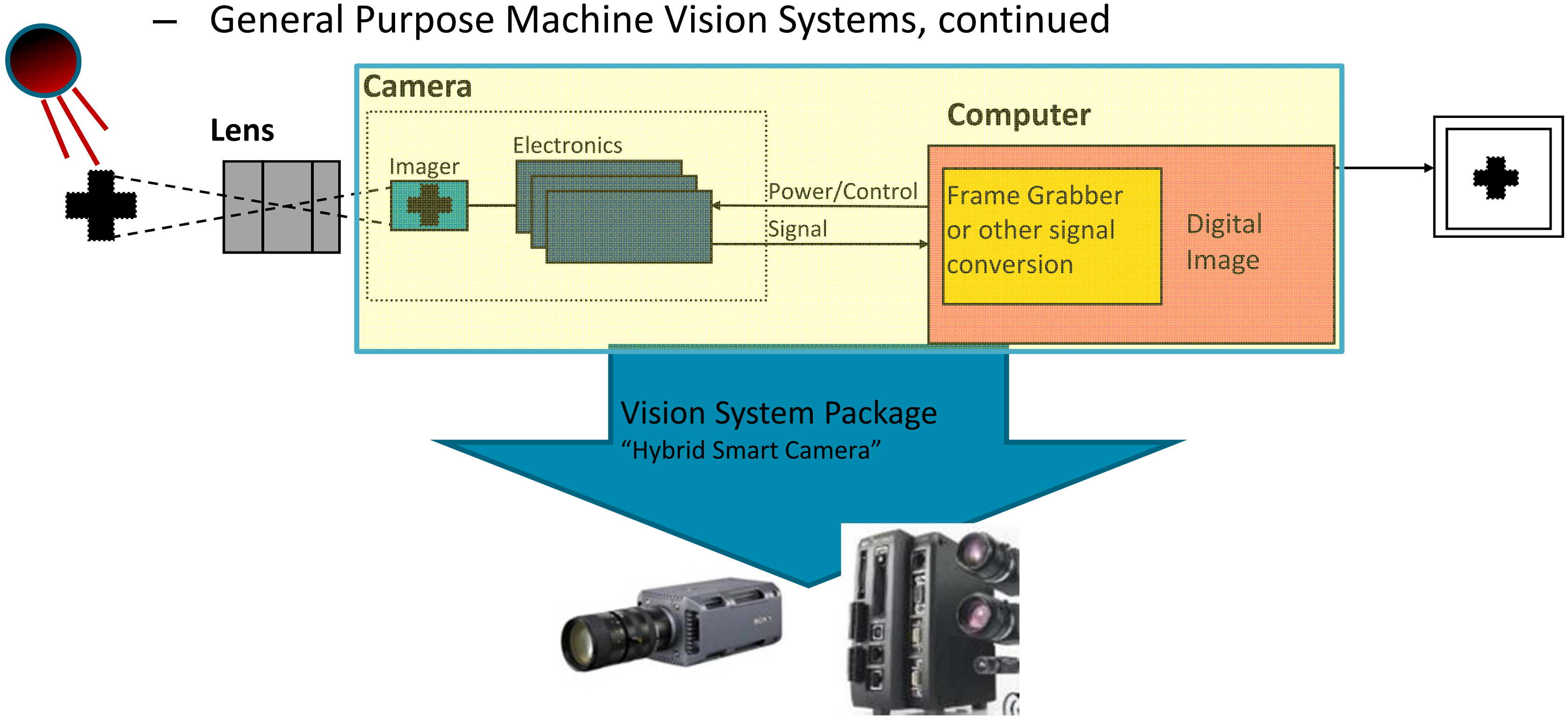
- The Machine Vision Market
  - General Purpose Machine Vision Systems, continued



  - Camera sensor and proprietary computer in one package, proprietary operating system, ethernet communications
  - Application configuration external to the device

Introduction and Overview

- The Machine Vision Market
  - General Purpose Machine Vision Systems, continued



  - Camera sensor or multiple tethered cameras with full computer (keyboard, mouse, monitor, USB, Ethernet), standard (Windows, Linux) or proprietary operating system,

Introduction and Overview

- The Machine Vision Market
  - System feature overview
    - PC-based systems
      - Most flexible and powerful system design
      - Degree of difficulty varies by implementation
      - Pricing varies depending upon architecture
    - Smart Camera/Smart Sensor vision system
      - Includes the easiest to use systems
        - » Some are more difficult to use
      - Greater danger of over-specifying capability
      - Pricing varies widely – can be quite inexpensive
    - Hybrid Smart Camera vision system
      - Includes some of the features of both depending upon product
      - Some architectures may pose integration challenges

Introduction and Overview

- The Machine Vision Market
  - Camera/processor hardware is just an “image delivery system”!!
    - Differentiation of products at the hardware level is limited to:
      - Physical structure and system architecture
        - » Single or multiple views?
          - Smart camera – distributed system
          - PC-based – centralized system
        - » Custom or fixed interface options
      - Available camera resolutions
      - Processing speeds
      - Input/output options
      - Other hardware integration issues

Introduction and Overview

- The Machine Vision Market
  - Peripheral components
    - Lighting
    - Optics
    - I/O devices
    - Frame Grabbers

Introduction and Overview

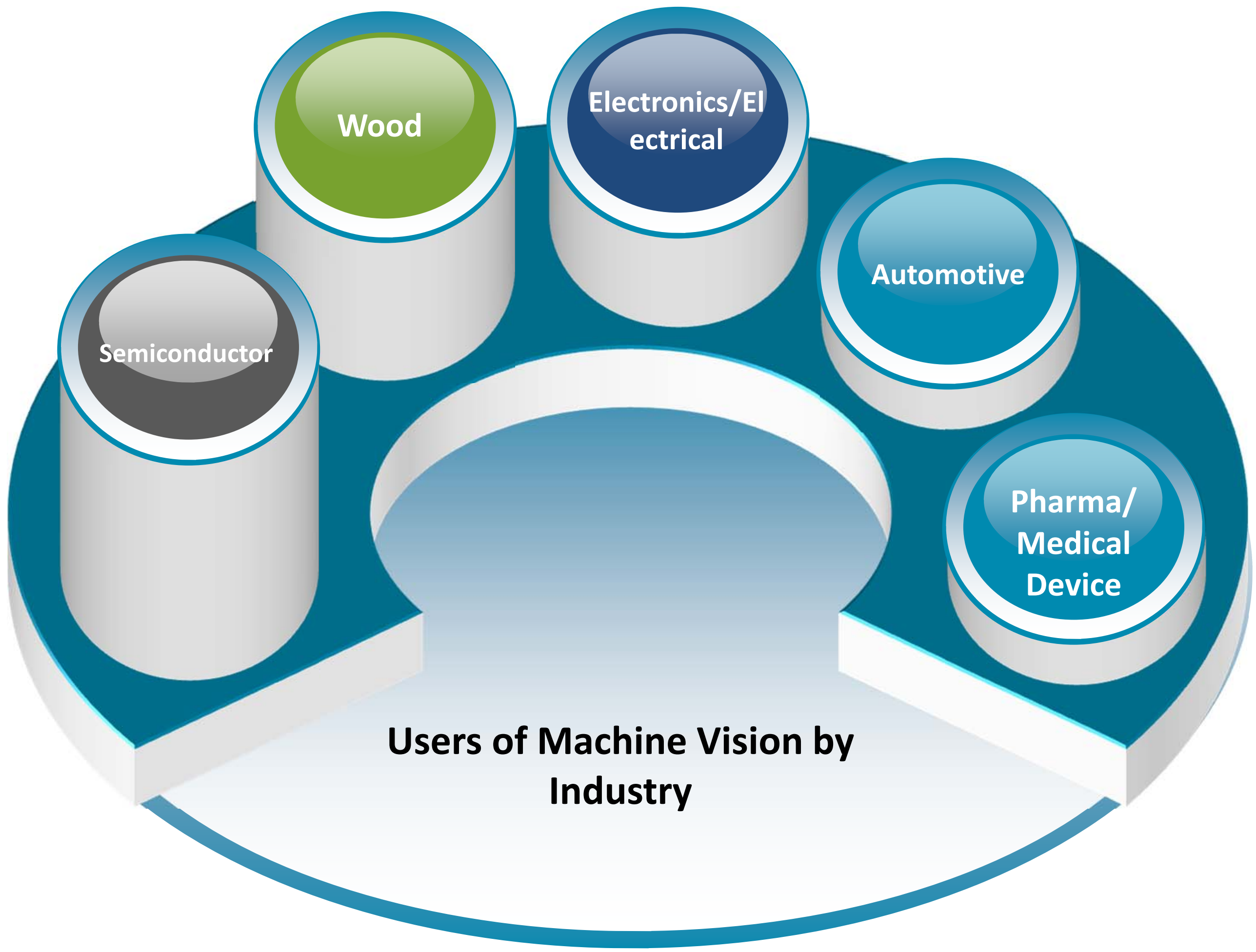
- The Machine Vision Market
  - Application Specific Machine Vision Solutions (ASMV)
    - Stand-alone devices designed for targeted inspection tasks
      - Imaging, lighting, optics, automation
    - Benefit is a generally uncomplicated and easy to use inspection device for a focused application area

Introduction and Overview

- The Machine Vision Market
  - Targeted application components
    - Bar- and 2D- code readers
    - Other “smart sensors”

Introduction and Overview

- Industrial Uses of Machine Vision



Introduction and Overview

- Industrial users of machine vision
  - Agriculture, Automotive, Biometrics/Security, Container, Cosmetic, Electronics/Electrical, Entertainment, Fabricated Metal, Fastener, Food/Beverage, Glass, Lab Automation, Lumber/Wood, Medical Devices, Medical Imaging, Military/Aerospace, Miscellaneous Mfg., Nanotechnology, Paper, Pharmaceutical, Plastics, Primary Metal, Printing, Rubber, Scientific Imaging, Semiconductor, Telecommunications, Textile/Apparel, Tobacco, Transportation

Introduction and Overview

- Industrial Uses of Machine Vision
  - Machine vision application categories
    - Defect detection
    - Gauging
    - Guidance and part tracking
    - Identification
    - OCR/OCV
    - Packaging inspection
    - Pattern Recognition
    - Product Inspection
    - Surface Inspection
    - Web Inspection

The Fundamentals of Machine Vision

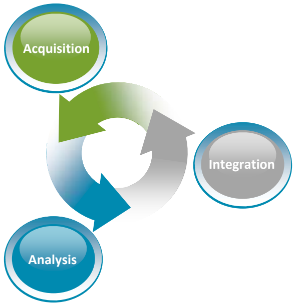


IMAGE ACQUISITION

– Sensors & Imaging
– Optics
– Lighting

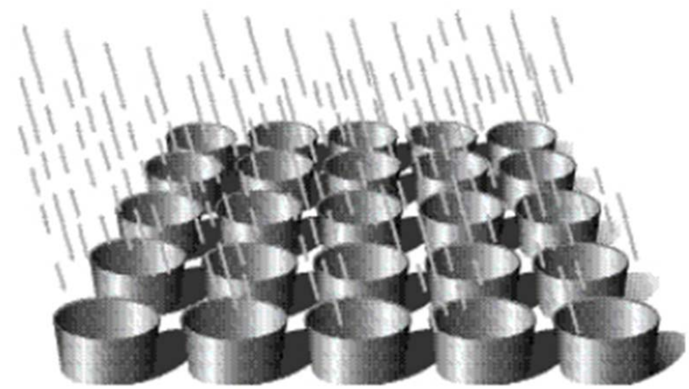
Image Acquisition

- Nothing happens in a machine vision application without the successful capture of a very high quality image
  - Image quality: correct resolution for the target application with best possible feature contrast
    - Resolution – determined by sensor size and quality of optics
    - Feature contrast – determined by correct lighting technique and quality of optics

  - Imaging is said to contribute more than 85% to the success of any machine vision application
  - The goal of machine vision image acquisition is to create an image that is usable by the technology – not necessarily one that's pleasing to the human eye

Image Acquisition

- Sensors and Imaging
  - All machine vision cameras create an image by exposing arrays of photosensitive material to light energy
    - Think of photon “buckets”
    - Exposure duration is time-limited and typically adjustable
    - The energy in a “bucket” captured during an exposure period becomes a micro-voltage for that “bucket”



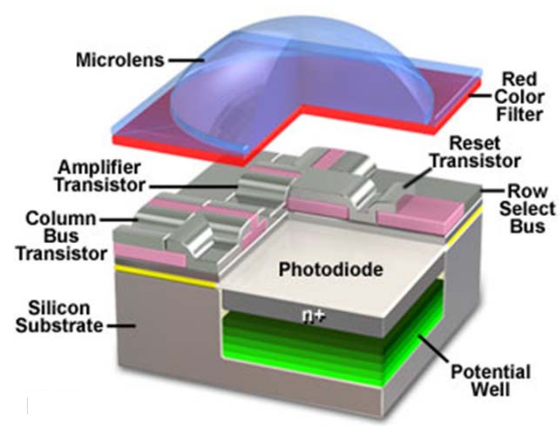


Image Acquisition

- Sensors and Imaging
  - Each element in a camera sensor array is called a pixel (picture element)
  - The energy value for each individual pixel is output as a micro-voltage upon acquisition of each image – the voltage ultimately determines the color level for that pixel
  - The pixel and data transfer architecture varies by sensor type
    - most widely used are CCD and CMOS

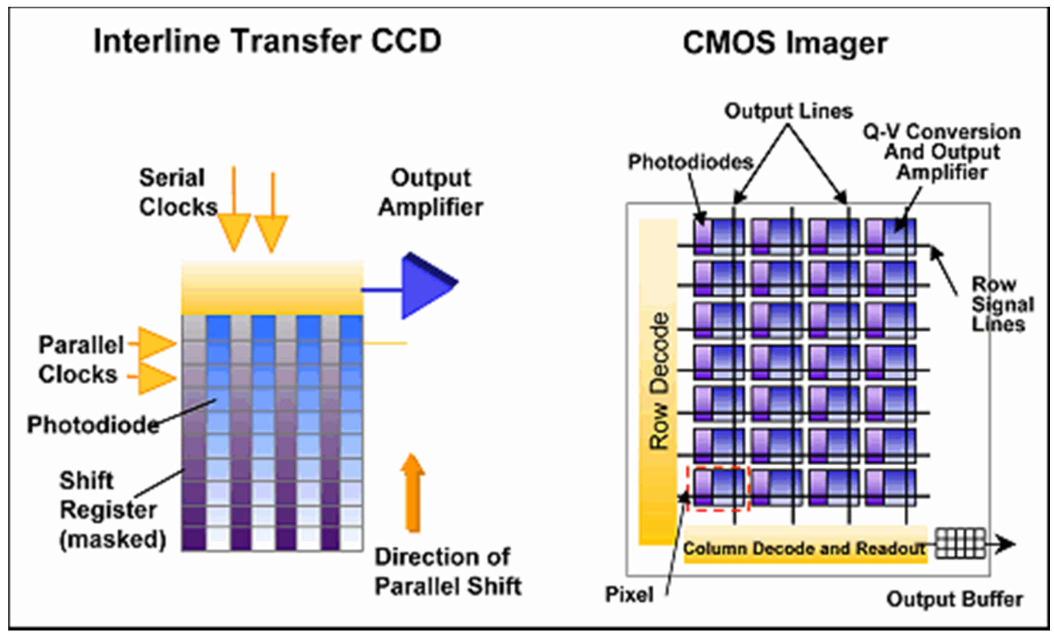
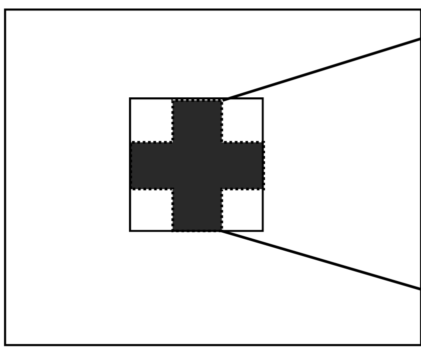


Image Acquisition

- Sensors and Imaging
  - The imaging sensor array comes in different physical layouts
    - Area
    - Line
  - Size of the chip varies widely as does the number of individual picture elements (pixels)
    - Typical area chip for machine vision: from .3 to 5+ Mpix
      - 640 to 2048+ pixels (horizontal)
      - Physical sizes from ¼” diag. up to 1”+
    - Typical line scan array: from 1K to 12K+ pixels
      - Physical sizes from about 15mm to 90mm+

Image Acquisition

- Sensors and Imaging
  - Image representation in the computer



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255	255	255	116	62	44	42	57	120	255	255	255
255	255	255	112	68	41	46	58	117	255	255	255
105	110	111	109	60	42	48	61	115	112	114	108
60	68	62	57	42	41	46	41	43	49	42	41
44	42	41	46	46	42	48	44	42	42	46	42
41	46	42	48	44	42	41	41	46	43	49	42
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100	120	120	115	51	41	43	49	110	116	118	105
255	255	255	118	62	44	42	57	115	255	255	255
255	255	255	121	68	41	46	58	120	255	255	255
255	255	255	100	60	42	48	61	105	255	255	255

Image Acquisition

- Sensors and Imaging

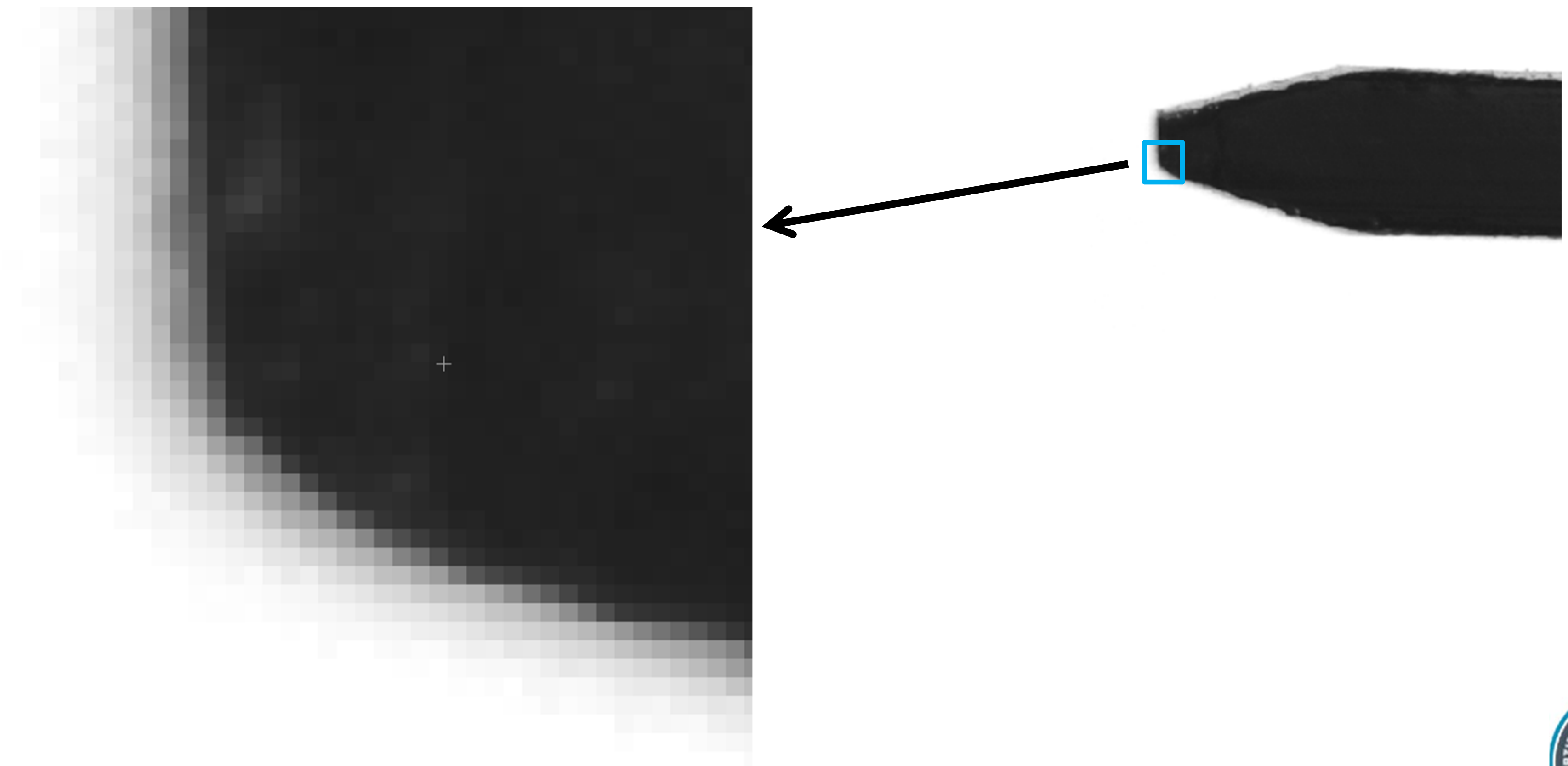
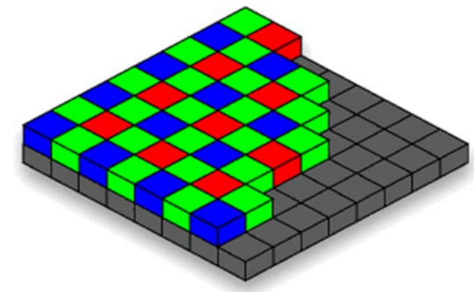
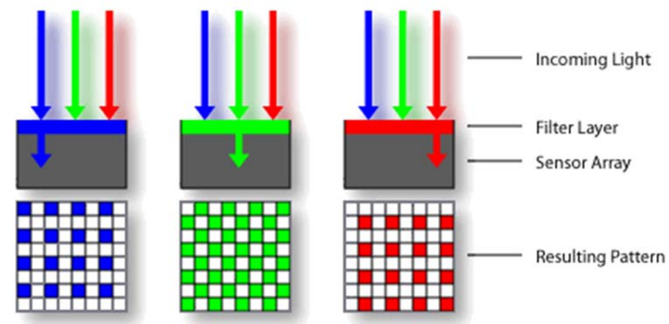


Image Acquisition

- Sensors and Imaging
  - What about color?
    - Bayer filter
    - Three-chip





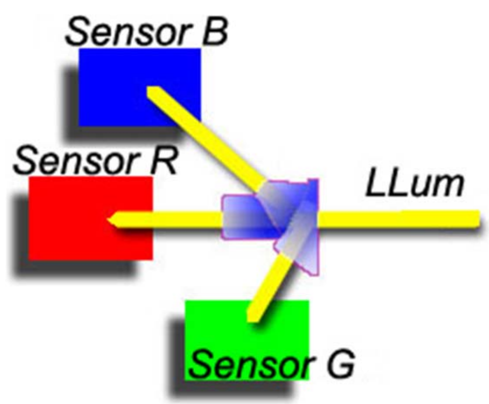


Image Acquisition

- Sensors and Imaging
  - Image resolution
    - Key element in vision component selection
    - The smallest feature resolved by the imager
    - Determinants: What is the size of the field of view (FOV), and what is the required accuracy of the imaging.

Imaged pixel size (relative to real world) = Field of View (FOV) / pixel count

- How many pixels? (for example only actual requirement varies by application

Inspection	Pixels required (usually)
Defect detection	Min. 2x2
Feature location	Min. 3x3
Feature differentiation	Min. 5x5
Gauging	Sub-pixel resolution must be $1/10^{th}$ the desired tolerance

Image Acquisition

- Sensors and Imaging
  - Image Resolution
    - Examples

We need to detect a 0.1” (diam.) defect (high contrast) on a surface that is 3’ square. Given good lighting and high-quality optics, what camera resolution do we need?

The defect diameter should span about 2 pixels so a pixel must cover 0.05”. Over 36” therefore, there must be 720 pixels (36 / 0.05). We must select a camera with at least that resolution in the minor axis (vertical) – probably one with a 1024x780 sensor.

We must differentiate an emblem that is approximately 1” high relative to a very similar feature in a low-contrast image. If we use a standard resolution camera (640 x 480), how large should the field of view be?

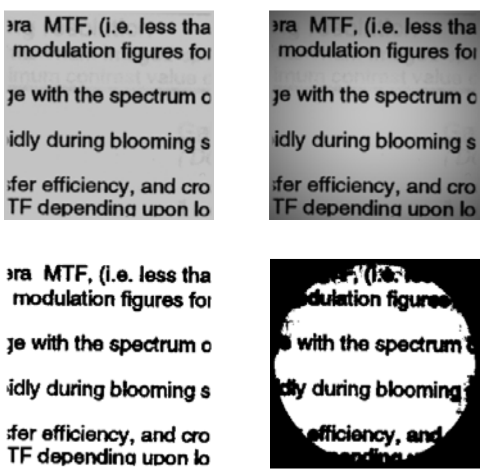
At minimum, a differentiable object must cover 5 pixels. Due to the low contrast, we decide to double that coverage to 10 pixels. The target pixel size will be 0.1” (1” / 10), and the field of view must be no larger than 48” (480 x .01).

Image Acquisition

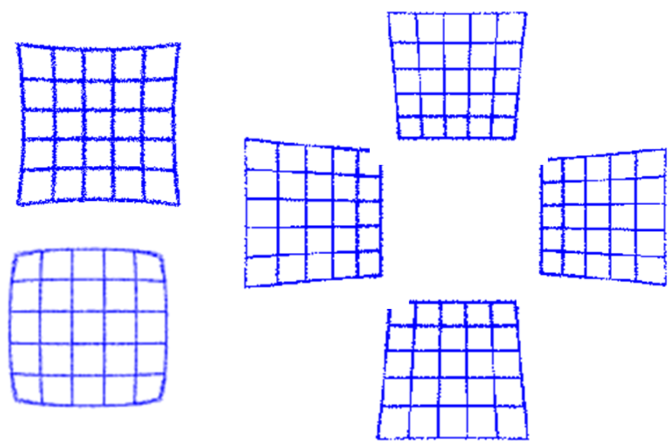
- Optics
  - Application of optical components
    - Machine vision requires fundamental understanding of the physics of lens design and performance
    - Goal: specify the correct lens
      - Create a desired field of view (FOV)
      - Achieve a specific or acceptable working distance (WD)
      - Project the image on a selected sensor based on sensor size – primary magnification (PMAG)
      - Create the highest level of contrast between features of interest and the surrounding background; with the greatest possible imaging accuracy

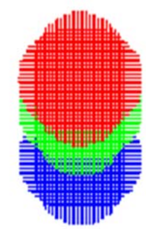
Image Acquisition

- Optics
  - Considerations for lens selection
    - Magnification, focal length, depth of focus (DOF), f-number, resolution, diffraction limits, aberrations (roll-off, chromatic, spherical, field curvature, distortion), parallax, image size, etc.
      - Some geometric aberration may be corrected in calibration
    - The physics of optical design is well known and can be mathematically modeled and/or empirically tested
      - Specification or control of most of the lens criteria is out of our hands



S5 S6

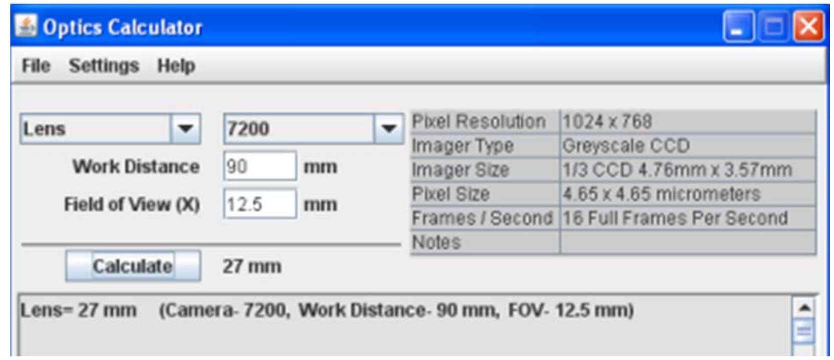


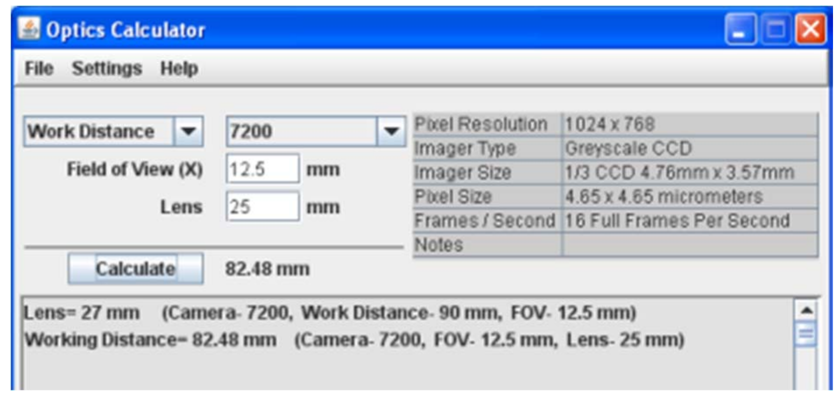


Images: Edmund Optics; www.edmundoptics.com

Image Acquisition

- Optics
  - Considerations for lens selection
    - Practical specifications for machine vision: PMAG (as dictated by focal length) and WD to achieve a desired FOV
      - Use a simple lens calculator and/or manufacturer lens specifications
      - Simple – state the required FOV, the sensor size based on physical selection of camera and resolution, and a desired working distance – calculate the lens focal length
        - » Note – specified working distance may not be available for a given lens – review specifications
      - Test your results
    - Always use a high-resolution machine vision lens NOT a security lens

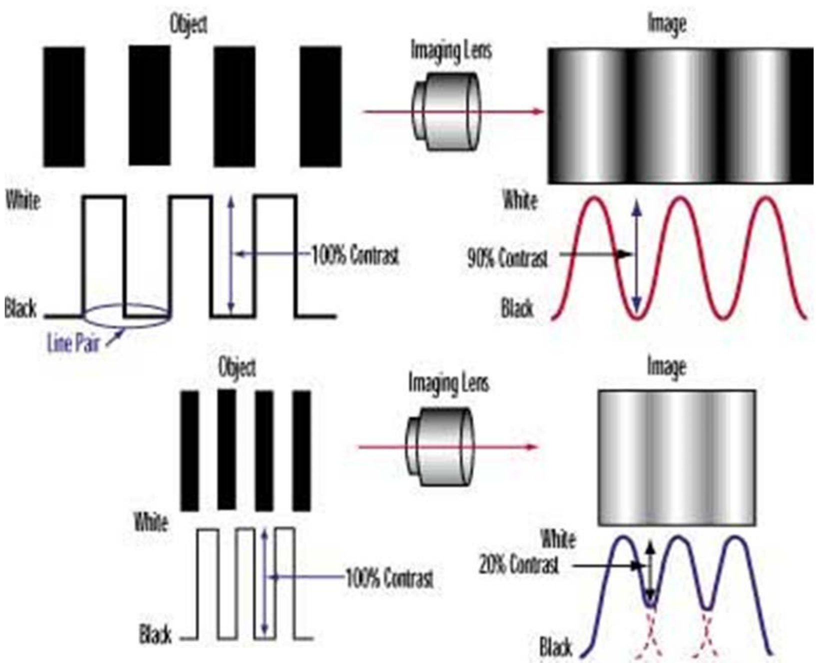




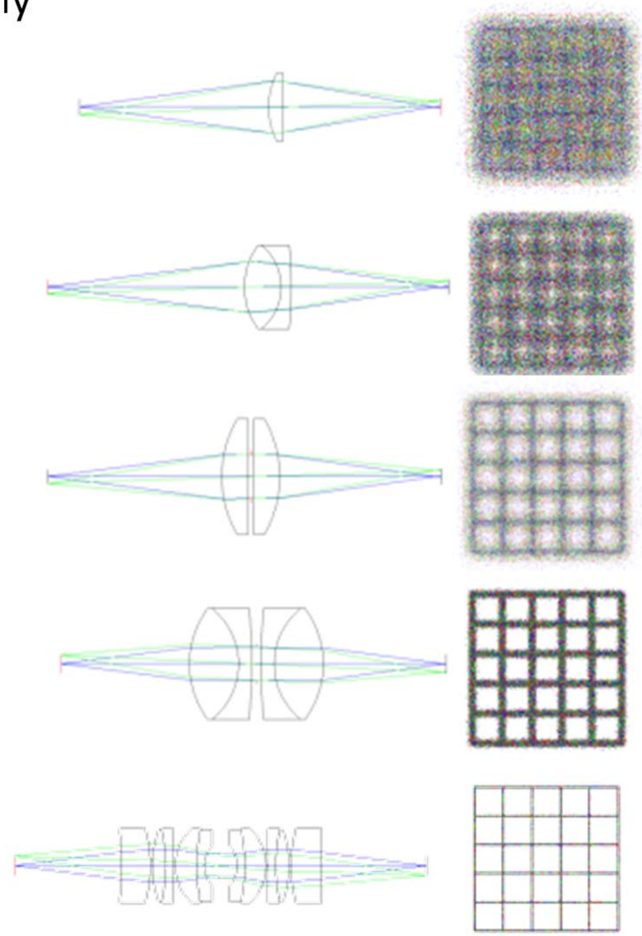
Images: PPT Vision; pptvision.com

Image Acquisition

- Optics
  - Why use machine vision lenses only
    - Light gathering capability and resolution



Images: Edmund Optics; www.edmundoptics.com



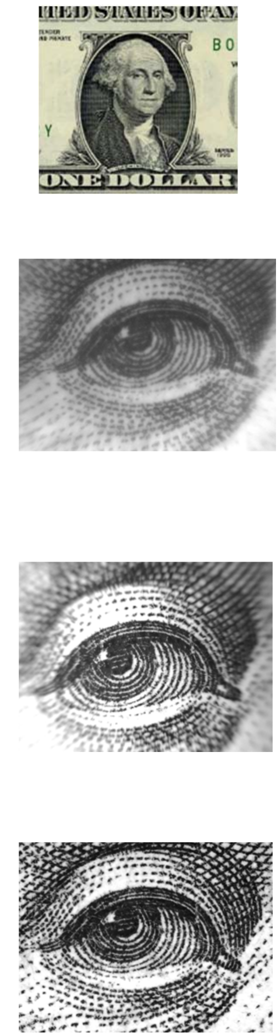
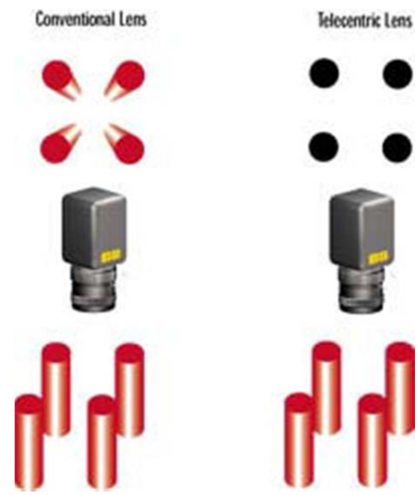
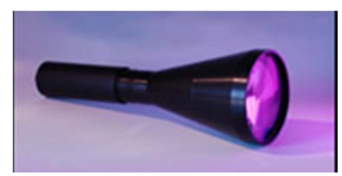


Image Acquisition

- Optics
  - Specialty Lenses
    - Telecentric
    - Microscope stages
    - Macro, long WD
    - Zoom (caution recommended)





Images: Edmund Optics; www.edmundoptics.com ,
Navitar; www.navitar.com

Image Acquisition

- Lighting
  - Science or art???
  - Correct lighting must
    - Highlight features to be detected relative to background
    - Create repeatable images regardless of part variation
  - Incorrect lighting will put the success/reliability/repeatability/ease-of-use of the vision application at risk
    - Machine vision cameras and software algorithms CANNOT make up for inadequate illumination techniques

Image Acquisition

- Lighting
  - Illumination for machine vision must be designed for imaging, not human viewing
    - Selection must be made relative to light structure, position, color, diffusion
    - We need to know how light works so our light selections are not "hit and miss" guesswork
    - Light is both absorbed and reflected to some degree from all surfaces
      - When an object is clear or translucent, light is also transmitted
      - Angle of incidence = angle of reflection

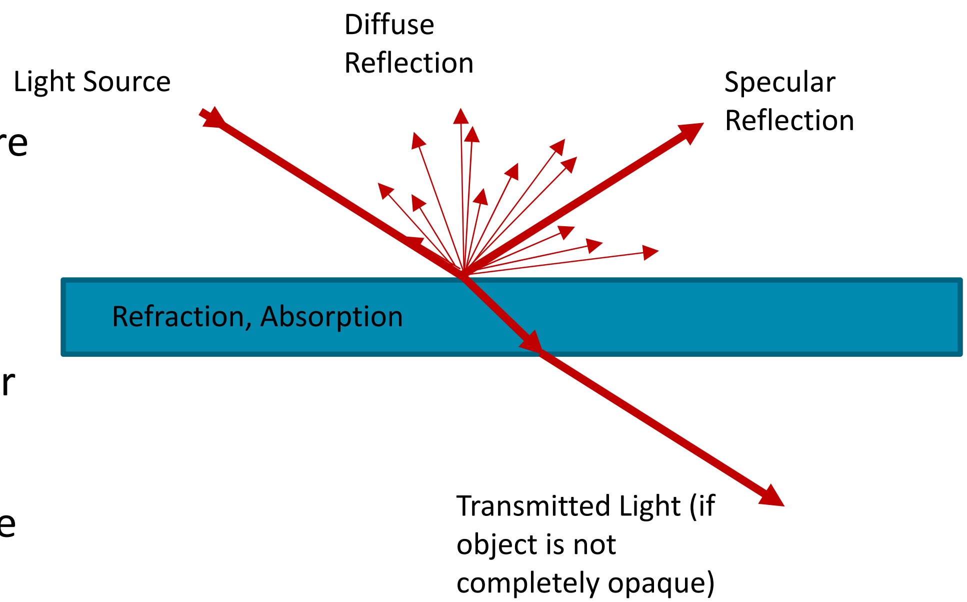


Image Acquisition

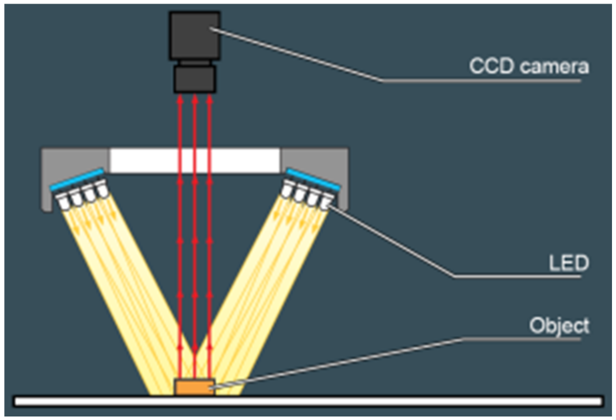
- Lighting
  - Dedicated lighting must be used for machine vision with few exceptions.
  - Where feasible, LED illumination is the best source
    - Long life with minimal degradation of intensity
    - Able to be structured into a variety of shapes
      - May be directional or diffuse
    - May be strobed at very high duty cycles and overdriven to many times nominal current specifications
    - Available in many visible and non-visible colors
  - Other sources – fluorescent, fiber-optics
    - Fluorescent – bright and highly diffuse but can be inconsistent
    - Fiber optic – glass/plastic fibers delivering light from halogen, tungsten-halogen or xenon source, bright, shapeable, focused

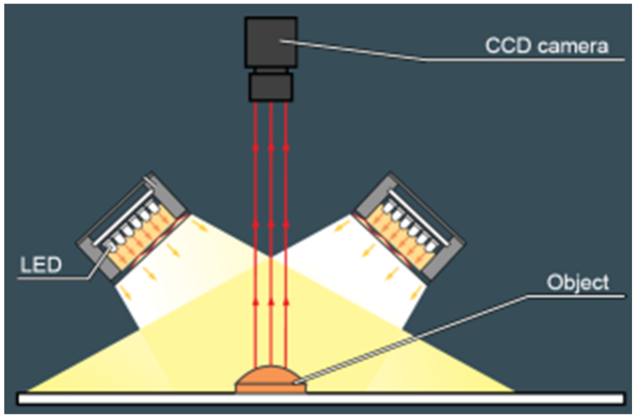
Image Acquisition

- Lighting
  - Lighting Techniques
    - The goal of lighting for machine vision applications usually is to maximize the contrast (grayscale difference) between features of interest and surrounding background
    - Techniques are categorized generally by the direction of the illumination source
      - Most may be achieved with different sources

Image Acquisition

- Lighting Techniques
  - Direct bright-field illumination
    - Sources: high-angle ring lights (shown), spot-lights, bar-lights (shown); LEDs or Fiber-optic guides
    - Uses: general illumination of relatively high-contrast objects; light reflection to camera is mostly specular

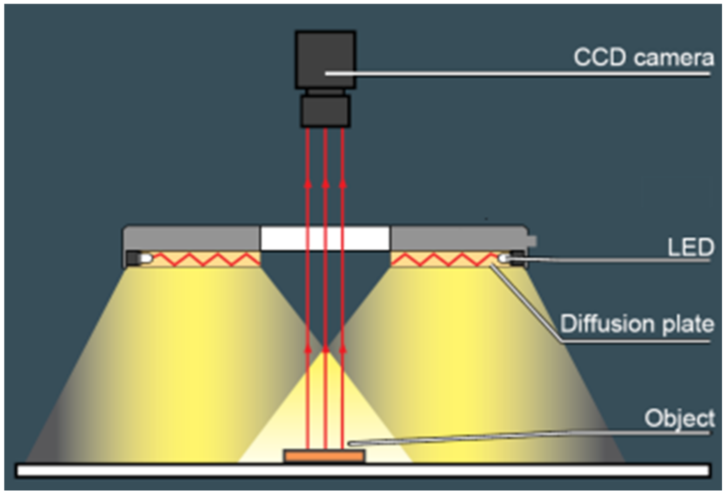




Images: CCS America; www.ccsamerica.com

Image Acquisition

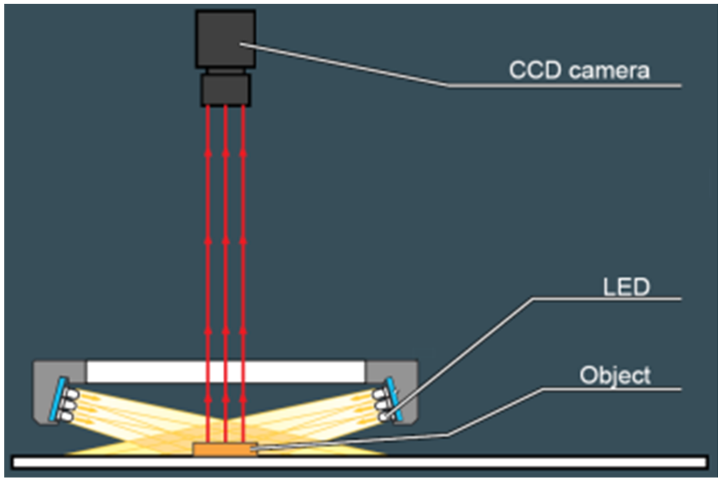
- Lighting Techniques
  - Diffuse bright-field illumination
    - Sources: high-angle diffuse ring lights (shown), diffuse bar-lights; LEDs or fluorescent
    - Uses: general illumination of relatively high-contrast objects; light reflection to camera is mostly diffuse



Images: CCS America; www.ccsamerica.com

Image Acquisition

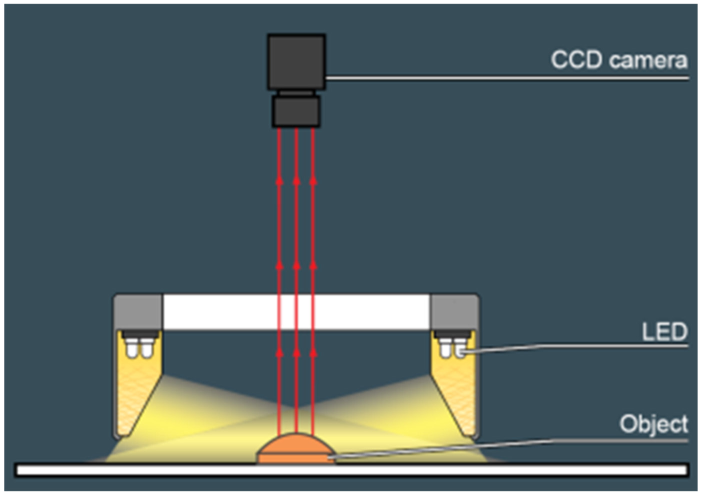
- Lighting Techniques
  - Direct dark-field illumination
    - Sources: low-angle ring lights (shown), spot-lights, bar-lights; LEDs or Fiber-optic guides
    - Uses: illumination of geometric surface features; light reflection to camera is mostly specular
    - “Dark field” is misleading – the “field” or background may be light relative to surface objects



Images: CCS America; www.ccsamerica.com

Image Acquisition

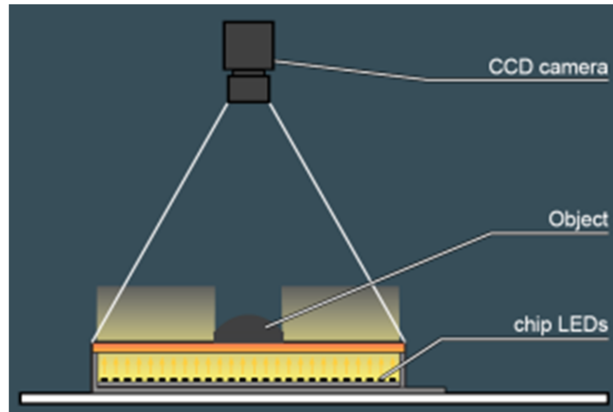
- Lighting Techniques
  - Diffuse dark-field illumination
    - Sources: diffuse, low-angle ring lights (shown), spot-lights, bar-lights; LEDs or fluorescent
    - Uses: non-specular illumination of surfaces, reducing glare; may hide unwanted surface features

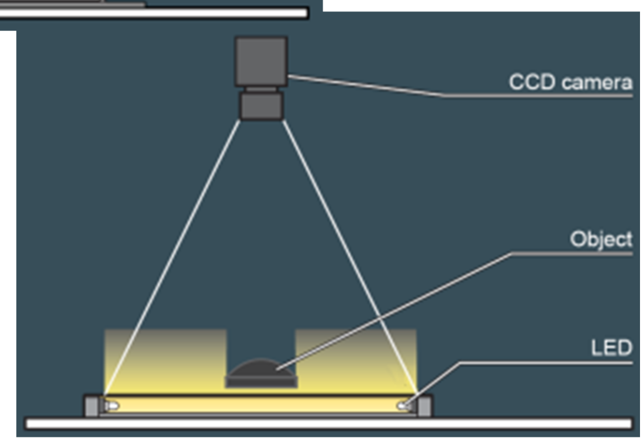


Images: CCS America; www.ccsamerica.com

Image Acquisition

- Lighting Techniques
  - Diffuse backlight
    - Sources: highly diffused LED or fluorescent area lighting
    - Uses: provide an accurate silhouette of a part

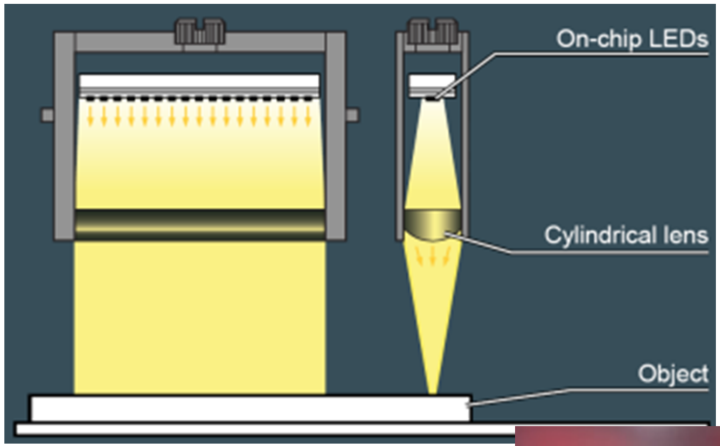


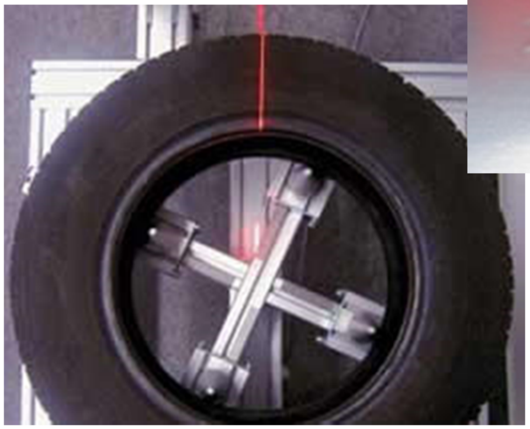


Images: CCS America; www.ccsamerica.com

Image Acquisition

- Lighting Techniques
  - Structured light
    - Sources: Focused LED linear array, focused or patterned lasers
    - Uses: highlight geometric shapes, create contrast based upon shape, provide 3D information in 2D images

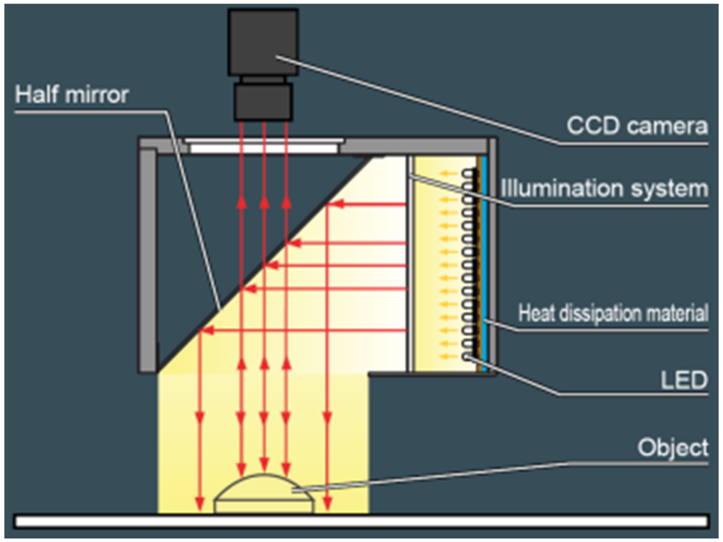




Images: CCS America; www.ccsamerica.com,
Stocker & Yale; www.stockeryale.com

Image Acquisition

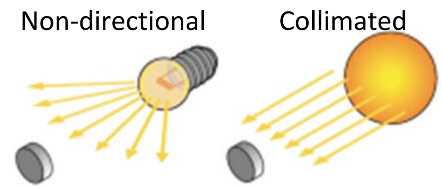
- Lighting Techniques
  - On-axis (coaxial) illumination
    - Sources: directed, diffused LED or fiber optic area
    - Uses: produce more even illumination on specular surfaces, may reduce low-contrast surface features, may highlight high-contrast geometric surface features depending on reflective angle

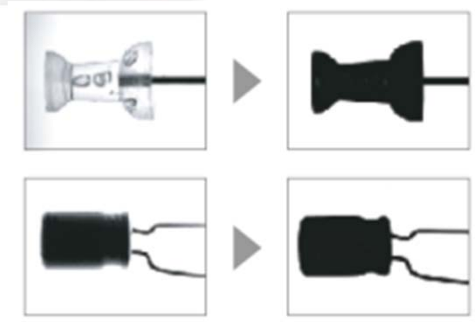


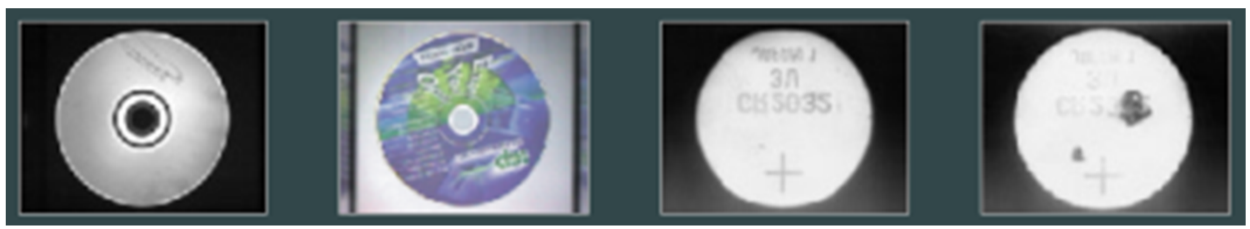
Images: CCS America; www.ccsamerica.com

Image Acquisition

- Lighting Techniques
- Collimated illumination
    - Sources: specialty illuminator (LED, Fiber) utilizing optics to guide the light
    - Uses: highly accurate backlighting, reducing stray light, highlighting surface features as a front light







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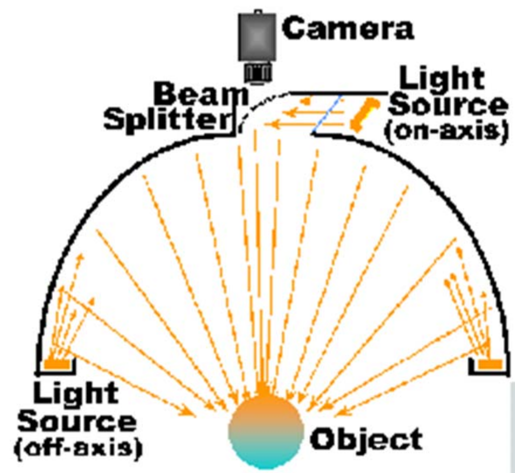
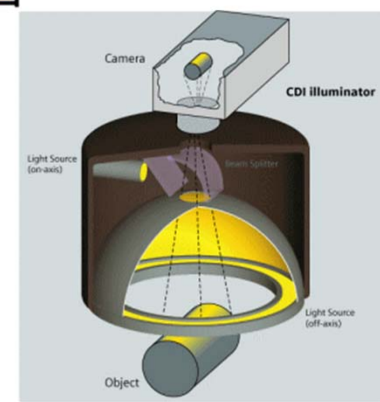
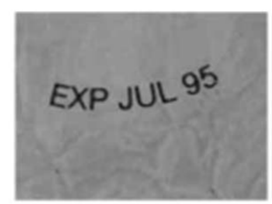
CCS America; www.ccsamerica.com

Image Acquisition

- Lighting Techniques
  - Constant Diffuse Illumination (CDI – "cloudy day illumination")
    - Sources: specialty integrated lighting
    - Uses: provides completely non-specular, non-reflecting continuous lighting from all reflective angles; good for reflective or specular surfaces



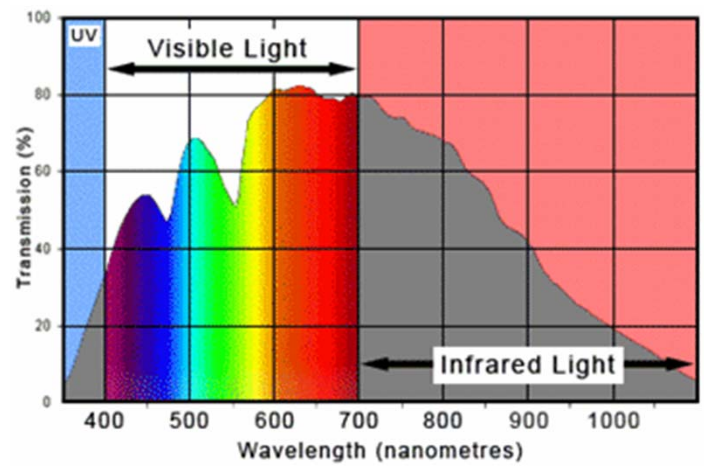


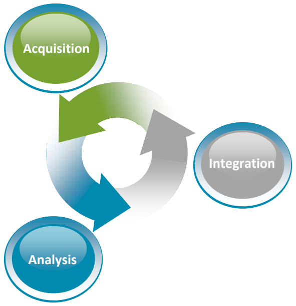


Images: Siemens; www.nerlite.com

Image Acquisition

- Lighting Techniques
  - Other lighting considerations
    - Color
      - Monochromatic light on colored features
      - Camera response to different colors
      - White light and color imaging
      - Non-visible “colors”
    - Light degradation over time; component life, heat dissipation
    - Light intensity and uniformity
    - Strobing
    - Elimination of ambient and other stray light





The Fundamentals of Machine Vision

IMAGE ANALYSIS

- Machine Vision Software
- General Machine Vision Algorithms

Image Analysis

- Machine Vision Software
  - Machine vision software drives component capability, reliability, and usability
  - Main machine vision component differentiation is in the software implementation
    - Available image processing and analysis tools
    - Ability to manipulate imaging and system hardware
    - Method for inspection task configuration/programming
    - Interface to hardware, communications and I/O
    - Operator interface and display capability
  - Often, system software complexity increases with system capability
  - AND greater ease of use usually is at the expense of some algorithmic and/or configuration capabilities

Image Analysis

- Machine Vision Software
  - A dizzying variety of software packages and libraries

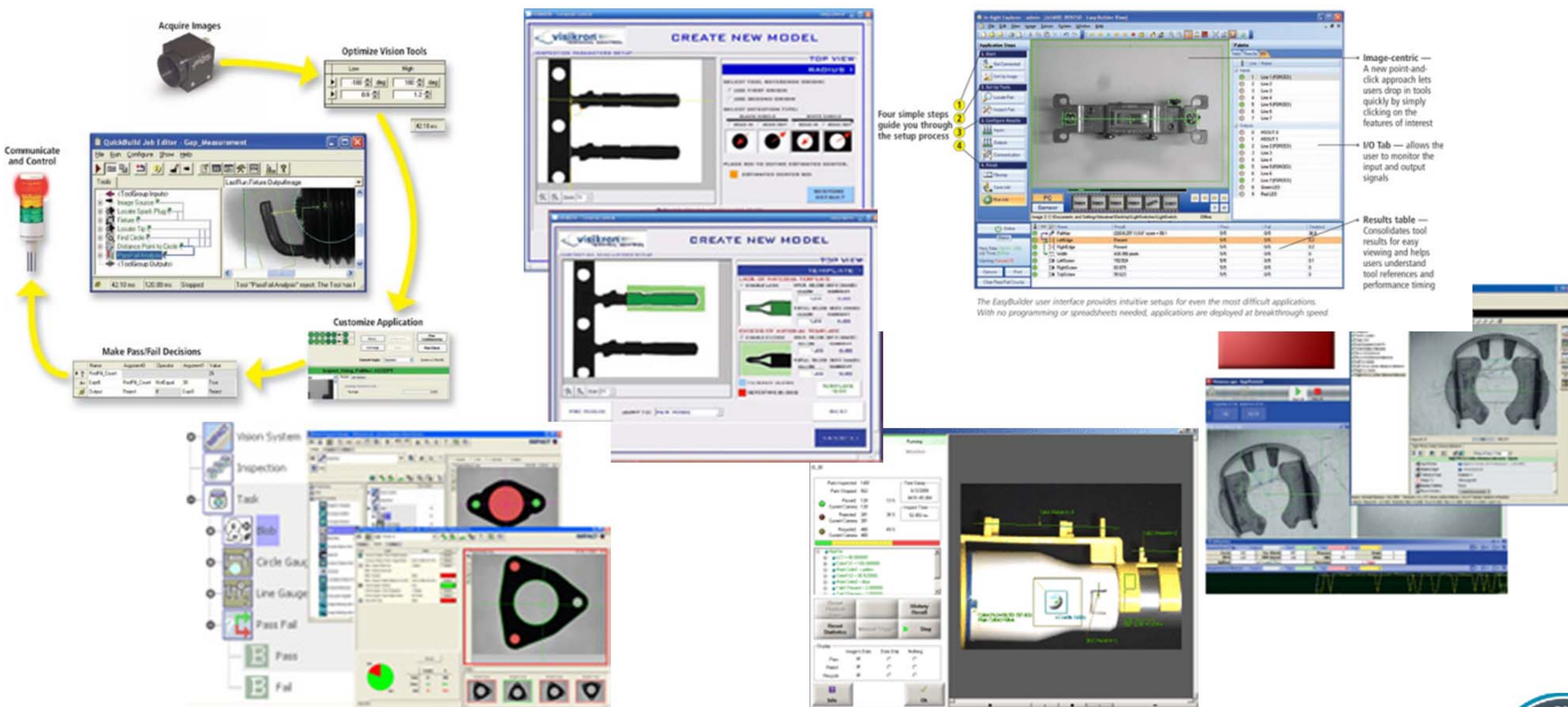
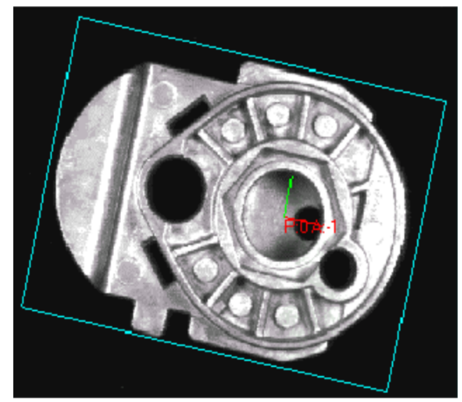


Image Analysis

- Machine Vision Software
  - What's Important
    - Sufficient algorithm depth and capability to perform the required inspection tasks
      - Consider:
        - » Speed of processing
        - » Level of tool parameterization
        - » Ease with which tools can be combined
    - Adequate flexibility in the process configuration to service the automation requirements
    - Enough I/O and communications capability to interface with existing automation as necessary
    - Appropriate software/computer interfacing to implement an operator interface as needed for the application

Image Analysis

- General Machine Vision Algorithms
  - Image transformation/geometric manipulation
  - Content Statistics
  - Image enhancement/preprocessing
  - Connectivity
  - Edge Detection
  - Correlation
  - Geometric Search
  - OCR/OCV
  - Color processing



  - Machine vision algorithms frequently execute over a subset of the image rather than the entire image. The area is often called a "region of interest" or ROI.

Image Analysis

- General Machine Vision Algorithms
  - Geometric manipulation of the image
    - Shifting
    - Rotating
    - Mirroring
    - Inverting
    - Unwrapping
    - Sampling
    - Binarization
    - Warping/Shifting

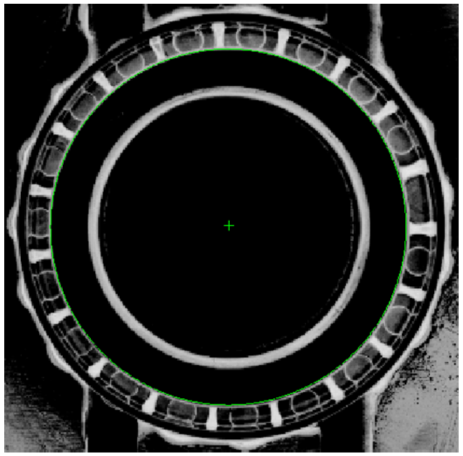
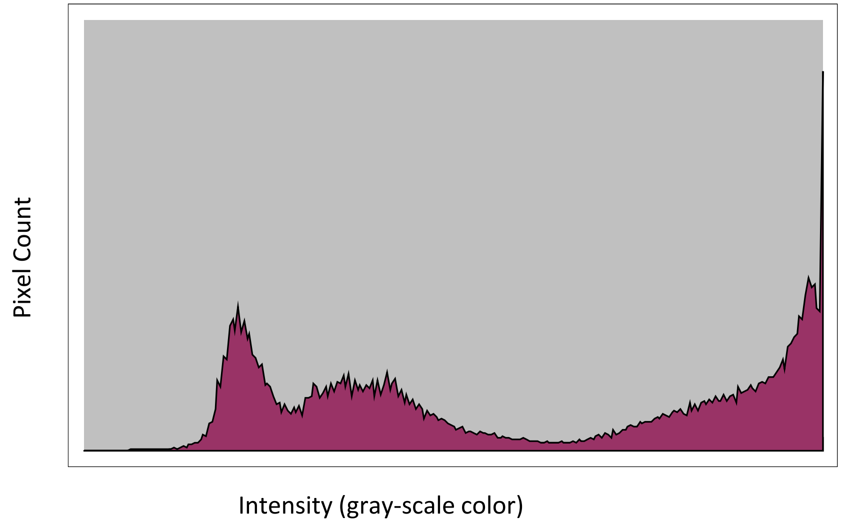


Image Analysis

- General Machine Vision Algorithms
  - Image/ROI content statistics
    - An image histogram shows the count of pixels at each gray-scale within either the image or a specified region.
    - The list can yield a variety of statistical information about the image or ROI.



Imaging Analysis

- General Purpose Machine Vision Algorithms
  - Applications of histogram statistics
    - Thresholding
    - Image equalization
    - Feature presence/absence
    - Surface analysis
    - Color/grayscale analysis
    - Lighting/camera status

Image Analysis

- General Purpose Machine Vision Algorithms
  – Image Enhancement/PreProcessing
    - Algorithms that change the image by physically replacing pixel values
      – Morphology
      – Spatial Filtering
    - Applications
      – Reduce noise
      – Create better contrast
      – Extract edge features

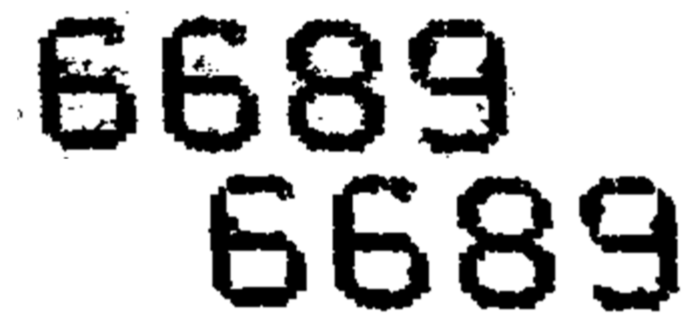


Image Analysis

- General Machine Vision Algorithms
  - Extraction and analysis of 2-dimensional connected shapes (blobs)
  - Connectivity can be a very useful and powerful tool
  - Success often depends upon the image and the level of pre-processing
    - Suited for images with high contrast and consistent color levels

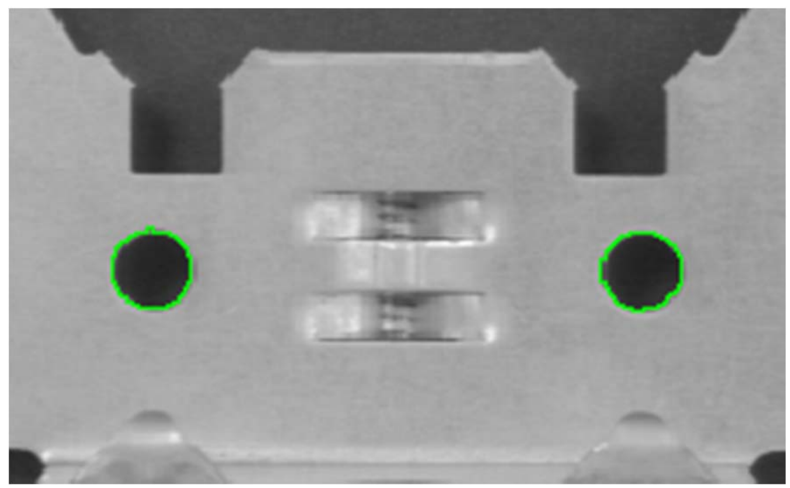


Image Analysis

- General Machine Vision Algorithms
  - Blob Statistics
    - Used to filter and categorize target shapes
      - Area
      - Perimeter
      - Center of Gravity, median
      - Bounding Box, Length, width, angle
      - Circularity, elongation, aspect ratio
  - Uses for Connectivity
    - Object location, identification
    - Cursory gauging
    - Presence/absence

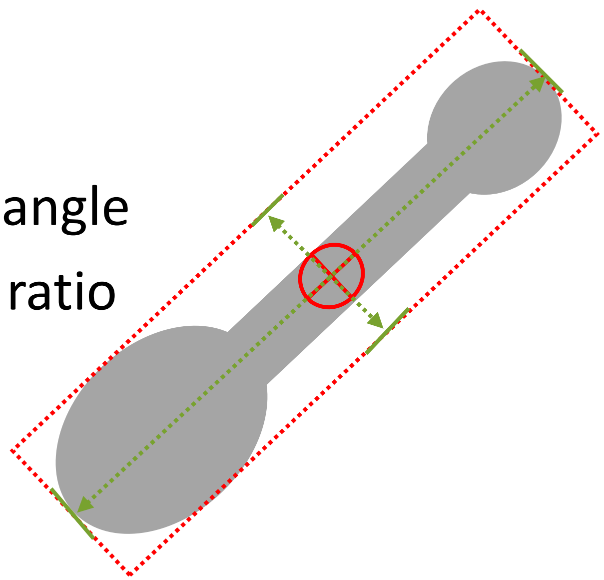
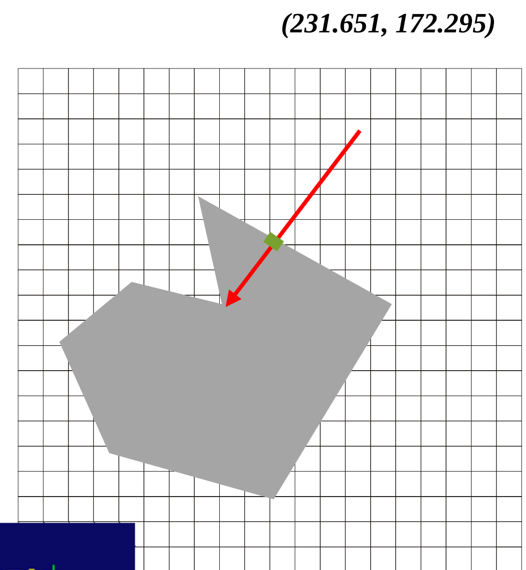
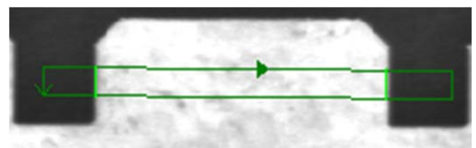


Image Analysis

- General Machine Vision Algorithms
  - Edge detection: isolation of local changes in contrast within the image
  - Edge tools locate whole or sub-pixel edge points
  - Uses for edge tools
    - Gauging
    - Feature presence, verification
  - Other edge tools
    - Line, curve or object approximation
      - Regressions
      - Hough transformation





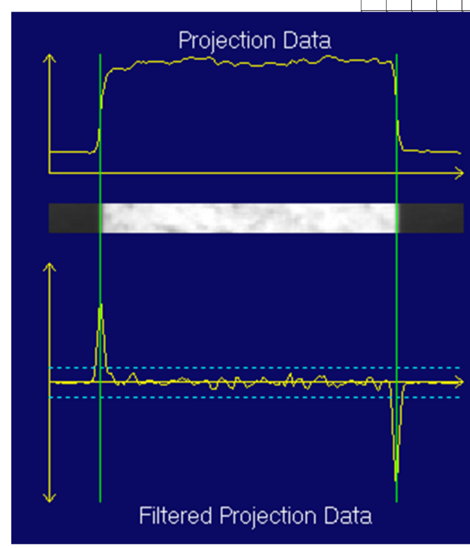


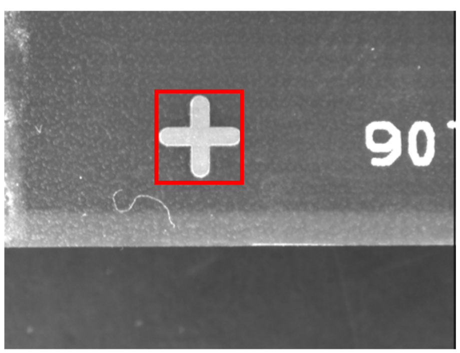
Image Analysis

- General Machine Vision Algorithms
  - Normalized Correlation
  - Finds pre-trained features
  - Other names
    - Template matching
    - Search
    - Pattern matching

Image Analysis

- General Machine Vision Algorithms
  - Normalized Correlation
    - A “model” or “template” is trained from an existing image
      - Models may be, but rarely are, synthesized
    - The model is stored as a complete gray-scale image
    - The target image or ROI is searched by mathematically comparing the model template at all points
    - Typical uses
      - Feature presence/absence
      - Position verification
      - Guidance

Target Image



Trained and Stored Model Template

Search Process

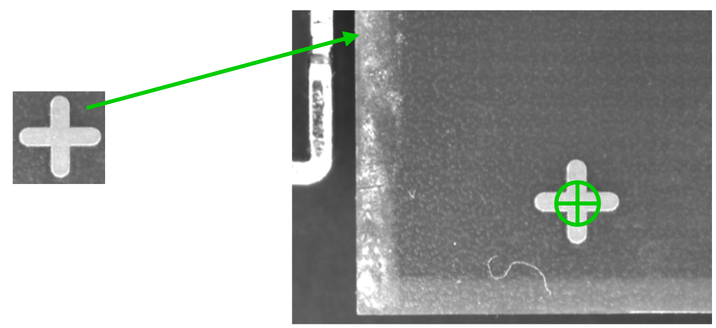
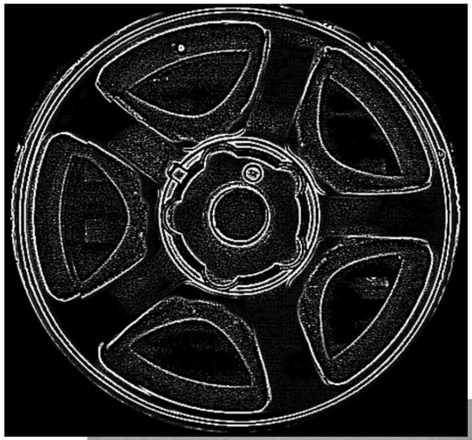


Image Analysis

- General Machine Vision Algorithms
  - Geometric Search
    - Locates features within an image based upon geometric structure, feature relationships
    - Also called pattern matching – algorithm has some branded
    - The search pattern is trained from an image or may be synthesized.
    - Geometric search pattern is a mathematical representation of the target object, not an actual image
    - Training and search process both use contour (e.g., edge) image
    - Process allows for fast, reliable search with full transformation and rotation.



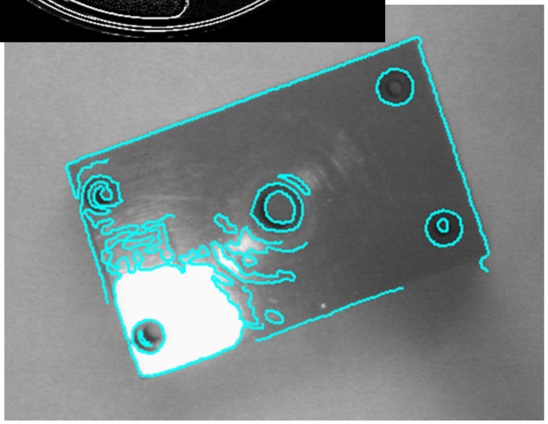
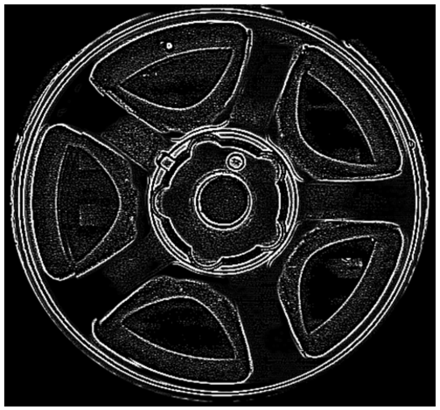
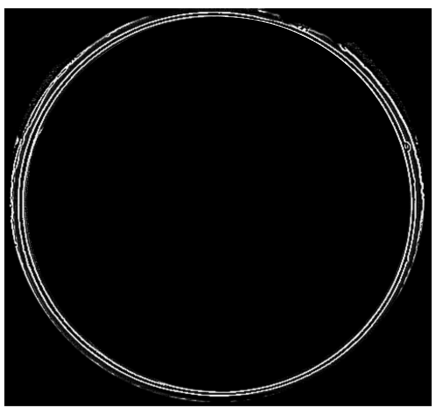


Image Analysis





- General Machine Vision Algorithms
  - Geometric Search
    - Pattern may be editable, or otherwise manipulated to optimize performance
    - Typical uses
      - Guidance
      - Feature location
      - Part verification

Image Analysis

- General Machine Vision Algorithms
  - Common challenges in search algorithms
    - Model selection
    - Confusing scenes

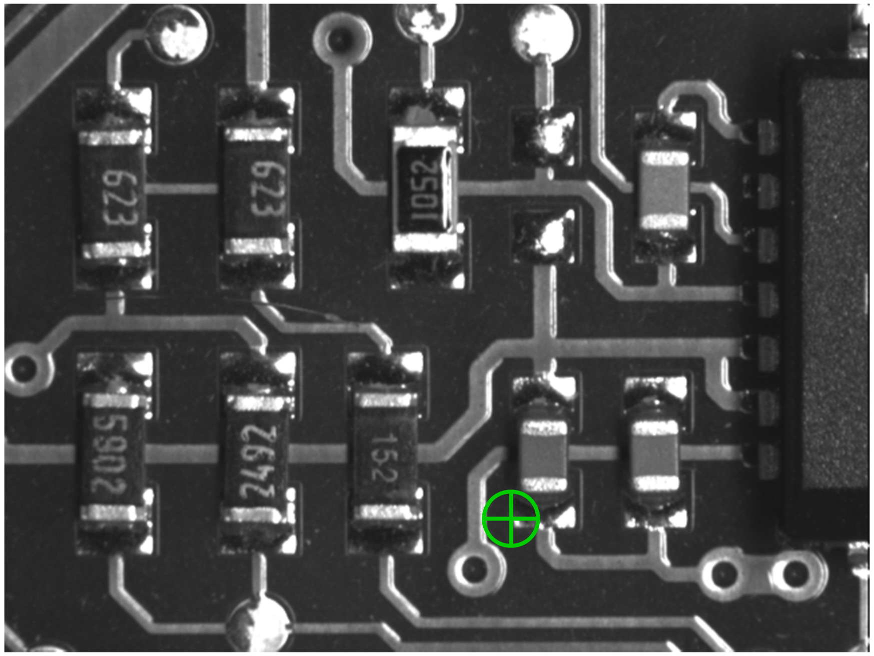
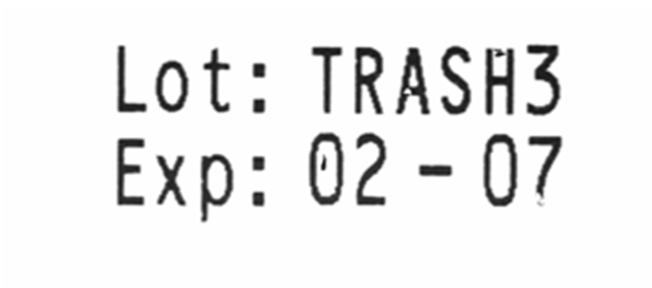
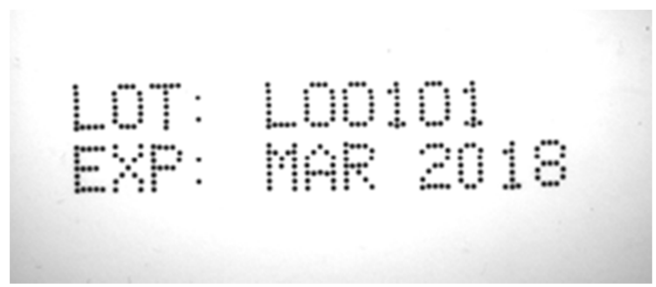
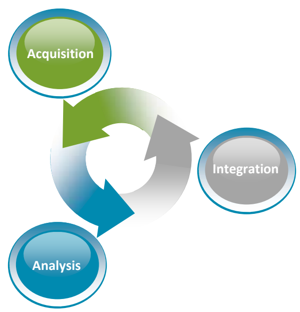


Image Analysis

- General Machine Vision Algorithms
  - OCR/OCV
    - Optical Character Recognition/Verification – reading or verifying printed characters
    - Can be fooled by print variations
    - Verification is difficult depending upon the application
    - Imaging Issues
      - Consistent presentation of the character string
      - May require extensive pre-processing





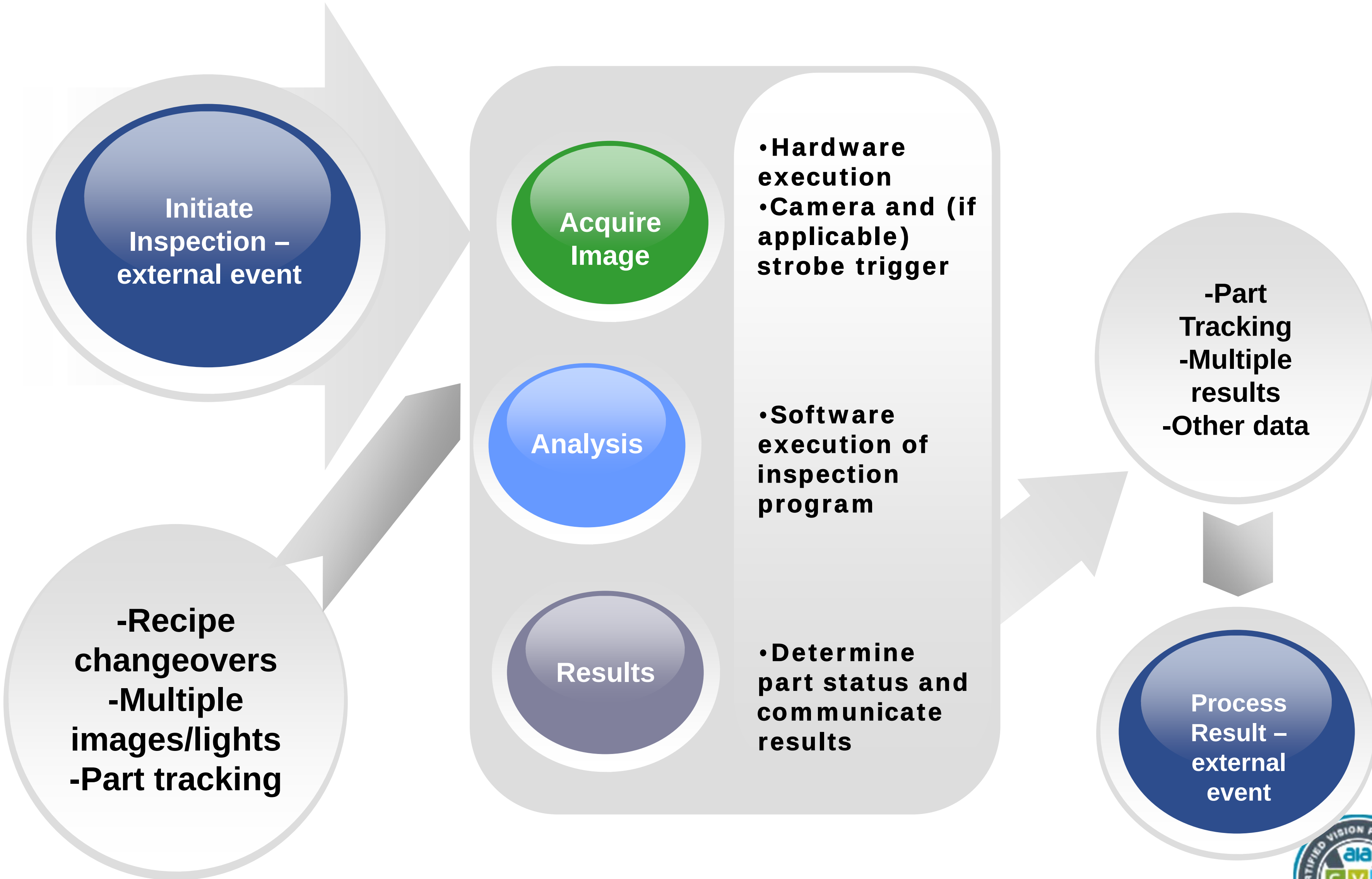


The Fundamentals of Machine Vision

INTEGRATION AND APPLICATIONS

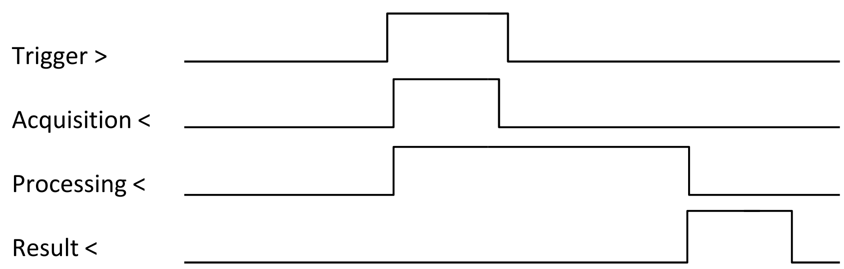
– Integration
– Results and Communications
– Basic Application Concepts

Integration and Applictions



Integration and Applications

- Integration
  - Utilize appropriate handshaking where applicable, particularly with interface to a PLC or external control system (not timers)
  - When part is in motion, interface from vision device to the automation must be discrete, digital I/O to avoid variable latencies



  - Other components – encoders/sensors/reject mechanisms

Integration and Applications

- Integration
  - Mechanical Issues
    - Camera/lighting fixturing
      - Incorporate adjustment as needed to accommodate the application requirements
        - » Goal: place camera on the specific plane required for the inspection at a point where the part can be triggered for the specified field of view, with lighting at the correct position relative to the camera
      - Often easier to adjust part sensor rather than camera
      - Fixtures must be robust and lockable
      - Some don'ts….

Integration and Automation

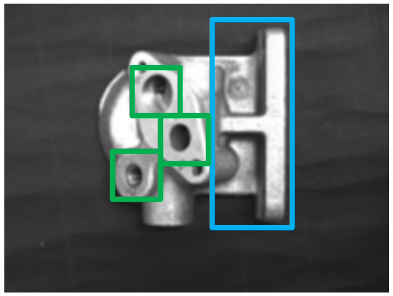
- Integration
  - Mechanical Issues
    - Part presentation
      - After lighting issues, part presentation is the most critical and difficult part of most industrial applications
        - » Direct impact on the lighting and imaging
        - » Part must be presented in a generally repeatable planar representation relative to the camera.
      - If new automation, incorporate appropriate part handling to enhance/benefit the inspection
      - Where possible modify existing automation to constrain part position

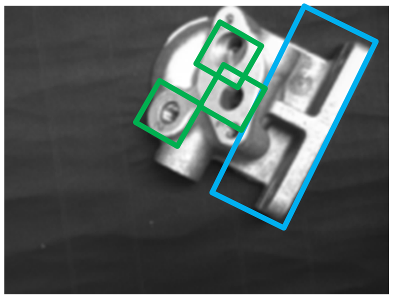
Integration and Automation

- Integration
  - Software and system configuration
    - Where possible, prepare a preliminary imaging set-up using the final lighting and optics configuration and capture real production images
    - Use production images for inspection program development
  - Configuring a basic machine vision inspection
    - Image acquisition/processing
      - Configure camera parameters
        - » Shutter, gain, offset, partial scanning, triggering
        - » Strobe light control
      - Execute an inspection process upon image acquisition
      - Tune the image if needed
        - » Filtering
        - » Morphology

Integration and Automation

- Integration
  - Configuring a basic machine vision inspection
    - Processing steps
      - Locate the part and extract a nominal origin
      - Adjust regions relative to the origin
      - Extract appropriate data within regions of interest
      - Make decisions based upon application parameters for that feature





Integration and Applications

- Results and Communications
  - Installation/testing/startup
    - Always implement control handshaking first
      - Image acquisition, data exchange, and reject timing/co-ordination make up the largest part of on-site systems integration with an automation device
      - Determine final camera/lighting mounting based upon live production imaging
        - » Lock/pin all mounts once image is correct for all parts
    - Test inspection algorithms on all samples with representative failure modes

Integration and Applications

- Results and Communications
  - Discrete digital I/O may be required due to timing/signal latency
  - Other communication protocols can be considered where appropriate
  - Incorporate proper handshaking when implementing signals with external control devices
  - Non-critical data communications (not requiring deterministic timing), such as part recipes, can be implemented with serial (RS232/422), TCP/IP, “Ethernet/IP”, or specialty (Modbus, DataHighway) interfaces.
  - The system design must take into account inherent latencies in these protocols
  - About “network” communications

Integration and Applications

- Basic Application Concepts
  - Configure the desired inspection task utilizing appropriate tools provided by the selected components
  - Typical general-purpose factory floor inspections
    - Flaw detection
    - Assembly Verification/Recognition
    - Gauging/Metrology
    - Location/Guidance
    - OCR/OCV
  - Note that virtually all applications will require the implementation of multiple "tools" to successfully extract the image data

Integration and Applications

- Basic Application Concepts
  - Defect/Flaw Detection
    - A flaw is an object that is different from the normal immediate background
    - Imaging Issues
      - Must have sufficient contrast and geometric features to be differentiable from the background and other "good" objects
      - Typically must be a minimum of 3x3 pixels in size and possibly up to 50x50 pixels if contrast is low and defect classification is required
      - Reliable object classification may not be possible depending upon geometric shape of the flaws
    - Machine vision tools
      - Binary pixel counting, morphology, edge extraction and counting, image subtraction/golden template, blob analysis

Integration and Applications

- Basic Application Concepts
  - Assembly Verification/Object Recognition
    - Feature presence/absence, identification, differentiation of similar features
    - Imaging Issues
      - Must create adequate contrast between feature and background
      - Accommodate part and process variations – locate and correct for part positional changes
      - May require flexible lighting/imaging for varying features
      - For feature presence/absence, feature should cover approx. 1% of the field of view (med. resolution camera), more for identification or differentiation
    - Machine vision tools
      - Edge detection and measurement tools, blob analysis, normalized correlation and pattern matching

Integration and Applications

- Basic Application Concepts
  - Gauging/Metrology
    - Note: There are physical differences between gauging features in an image produced by a camera, and the use of a gage that contacts a part. These differences usually can not be reconciled
    - Gauging concepts
      - Resolution, repeatability, accuracy
      - Sub-pixel measurement
      - Measurement tolerances
      - Resolution must be approximately 1/10 of required accuracy in order to achieve gauge reliability/repeatability

Integration and Applications

- Basic Application Concepts
  - Gauging/Metrology
    - Imaging Issues
      - Lighting to get a repeatable edge
        - » Backlighting, collimated light
      - Telecentric lenses
      - Calibration
        - » Correction for image perspective/plane
        - » Calibration error stack-up
    - Machine vision tools
      - Edge detection and measurement, blob analysis

Integration and Applications

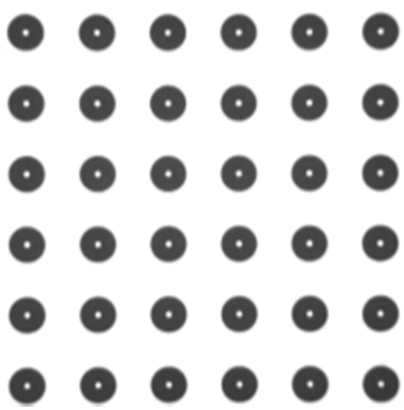
- Basic Application Concepts
  - Location/Guidance
    - Identification and location of an object in 2D or 3D space
    - May be in a confusing field of view
    - Imaging Issues
      - Measurement tolerances and accuracies as described for gauging/metrology applications
      - Sub-pixel resolutions may be better than discrete gauging results
      - For guidance applications, the stack-up error in robot motion may be significant
    - Machine vision tools
      - Blob analysis, normalized correlation, pattern matching

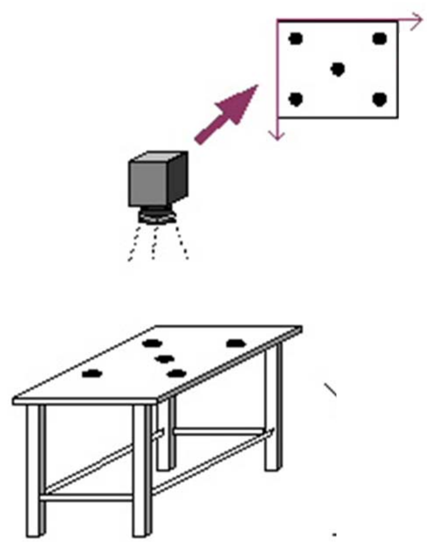
Integration and Applications

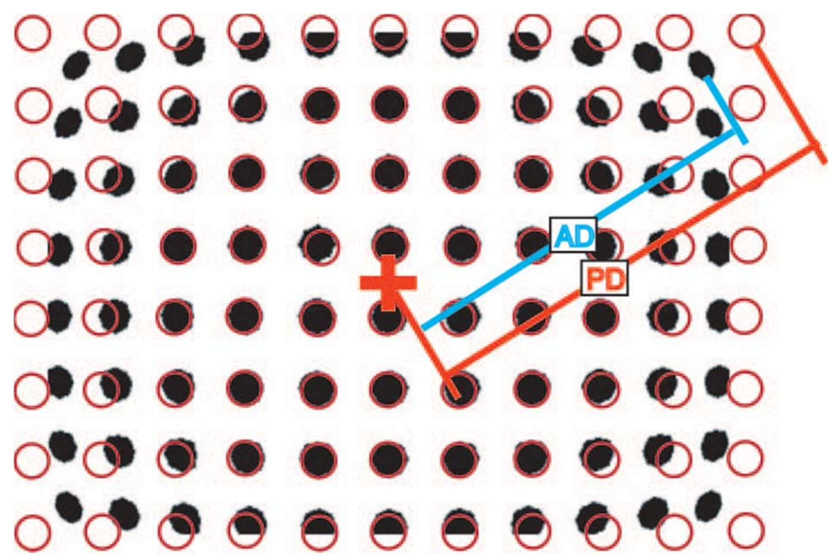
- Basic Application Concepts
  - OCR/OCV
    - Optical Character Recognition/Verification – reading or verifying printed characters
    - Can be fooled by print variations
    - Verification is difficult depending upon the application
    - Imaging Issues
      - Consistent presentation of the character string
      - May require extensive pre-processing
    - Machine vision tools
      - OCR/OCV, golden template match

Integration and Applications

- Basic Application Concepts
  - Camera Calibration
    - Mapping real-world coordinates to the camera (observed) pixel coordinates
    - Correction of planar and optical distortion





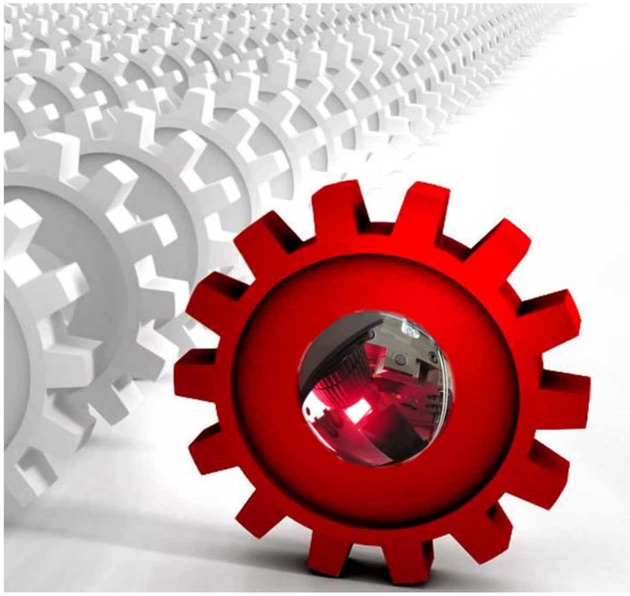


Images: Edmund Optics; www.edmundoptics.com,
Cognex; www.cognex.com

Conclusion

- Where do we go from here?

Questions…



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