INDUSTRIAL IMAGE PROCESSING 2D & 3D

Renè Klausrigler
Productmanagement „Identification & Measuring“
April 2020
NOTES ON THE WEBINAR

- The Webinar will be recorded!
- If you would like to receive the presentation and / or the recording afterwards you have to sign GDPR!

https://s.sick.com/newsletter_registration_at-de
INDUSTRIAL IMAGE PROCESSING 2D & 3D CONTENT

- **BASICS (2D – image processing)**
  - Working principle (explanations)
  - Focal length & Lens
  - Focus, aperture, depth of field
  - Image-, sensor and object resolution
  - Exposure, gain, blur, resolution, repeatability and accuracy

- **2. LIGHTING PRINCIPLES (2D – image processing)**
  - Basics (importance of light....)
  - Different kind of lightings (ring light, dark field illumination, backlight...)

- **3. TARGET APPLICATION / PRODUCT PORTFOLIO (2D – image processing)**
  - 2D Vision
4. BASICS (3D – image processing)
   ▶ Working principle “Triangulation“
   ▶ Working principle “Time of flight“
   ▶ Working principle “Stereo“
   ▶ When to use 3D technology

5. TARGET APPLICATION / PRODUCT PORTFOLIO (3D – image processing)
   ▶ Configurable cameras
   ▶ Programmable cameras
   ▶ Streaming cameras
INDUSTRIAL IMAGE PROCESSING 2D & 3D

1. WORKING PRINCIPLE

- Image processor
- Image buffer
- Housing
- Optics
- Electrical connection
- Data output
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1. CAMERA TYPES BY DIMENSION

- **1D (line scan)**
  - Collects gray or color profiles
  - Profiles can be assembled into an image => 2D
  - Scanning requires object movement

- **2D**
  - Acquires an area image
  - Snapshot "click", no movement needed

- **3D**
  - Outputs a 3D image as a height map (seen from one direction) or a point cloud (360° imaging)
  - Can be snapshot (stereo) or scanning (laser triangulation)

- **MultiScan**
  - 1D, 2D, 3D and more with the same camera, at the same time
1. EXPLANATIONS (FOV, WD/RD, DOF)

- **Field of view (FOV)**
  - Is what the camera sees (x & y)

- **Working or Reading Distance (WD/RD)**
  - The Working Distance (WD) or Reading Distance (RD) is the lens-to-object distance

- **Depth of Field (DOF)**
  - Is the range in which a sensor can read a code, without changing focal position or lens.
The view angle of the lens determines how much of the visual scene the camera sees:

- Wide angle (short focal length) captures a large scene
- Normal
- Narrow angle, or tele (long focal length), captures a small scene
1. EXPLANATIONS (FOCAL LENGTH AND LENS)

- **Dependency**
  - Focal length ↔ Field of view

Looking at a computer keyboard with different lenses

Focal length: 4.3 mm
Focal length: 6 mm
Focal length: 10 mm
Focal length: 16 mm
A sharp image is well focused

- The focus is used to sharpen the image. There are various types of focuses.

Example:
1. EXPLANATIONS (TYPES OF FOCUSES)

- **Fix Focus**
  - The focus is set to a certain reading distance and can not be changed.

- **Mechanical Focus**
  - The focus can be changed mechanically during commissioning.

- **Dynamic Focus**
  - The focus can be changed during the reading gate by command or incoming event such as hardware input.

- **Teach Auto Focus**
  - The focus can be set automatically by the device, but only when commissioning the device NOT during reading mode.

- **Auto Focus**
  - The focus is automatically done by the device even during reading gate / trigger.
1. EXPLANATIONS (APERTURE)

- The aperture is the hole inside the optics through which the light enters the camera
- A small hole means a high aperture number (e.g. f/12)

- Small hole → High aperture number → small amount of light → darker image
- Big hole → Small aperture number → big amount of light → brighter image

- Example
  - Aperture: f/4.5
  - Aperture: f/28
The “Depth of Field” (DOF) is the range in which a scene appears acceptably sharp.

Within the DOF, a sensor can read a code or detect an object, without changing focal position or lens.

The depth of field depends on
- Focal length / Focal position
- Working / Reading distance
- Lens
- Aperture
- Camera sensor resolution

Main effects
- Large aperture → small DOF / Small aperture → large DOF
- Long focal length → small DOF / Short focal length → large DOF
- Short working distance → small DOF / Long working distance → large DOF
1. PIXEL INFORMATION

- **Black and white** – binary values, 0 or 1
  
  ![Black and white pixel values](image)

- **Gray scale** – values from 0 to 255
  
  ![Gray scale pixel values](image)

- **Color** – RGB (Red, Green, Blue), each channel has a value from 0 to 255
  
  ![Color pixel values](image)
1. OBJECT RESOLUTION

- **Object resolution**
  - Physical dimension on the object, that corresponds to one pixel on the sensor (mm/pixel)
  - → Which length (mm) is equal to one pixel

- **Example**
  - FOV size
    - Width (x): 50 mm
    - Height (y): 37.5 mm

- **Sensor resolution**
  - Width (x): 640 px
  - Height (y): 480 px

- **Object resolution (by width)**
  - 50 mm / 640 px = 0.08 mm/pixel
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1. EXPOSURE / GAIN

- **Exposure is the amount of light that is recorded by the sensor**

- **Exposure depends on**
  - Exposure time
  - Aperture size
  - Object illumination
  - Sensor’s light sensitivity

- **Electronic gain**
  - Increased gain allows shorter exposure time, but amplifies noise

![Images showing underexposed, normal, overexposed, normal gain, and high gain conditions](image-url)
### 1. BLUR

**Blur is caused by**
- Lens is out of focus
- Motion
- Camera shake (e.g. vibrations)

**Blur is avoided by**
- Focus adjustment
- Short exposure time + intense light
- Mount separately from vibrating machine

![Blurred images](image1)

**Reduced exposure time**
**Use stronger light**
Resolution, repeatability and accuracy are connected, but not the same

- Off-set compensation makes accuracy = repeatability
  - Requires that the true value (bull’s eye) is known from a reference method
1. PROCEDURE TO ACHIEVE ABSOLUTE ACCURACY

- **First get good repeatability**
  1. Ensure a good image quality
  2. Calibrate the setup with a checkerboard target
  3. Make >10 measurements on the same object to see the repeatability
  4. Improve the repeatability if needed

- **Then go from repeatability to accuracy**
  5. Measure the object(s) with a trusted reference method
  6. Calculate the average measurement error (off-set)
  7. Subtract the error by ”off-set compensation”

![Diagram showing the process from poor image to good accuracy](image-url)
2. THE IMPORTANCE OF LIGHT

- Just like the eye, machine vision depends on light and optics to work

- Different lighting methods can have very different visual effects

- The success of an application often depends on the image quality, which depends on a good lighting method

- Which method is "right" depends on the surface characteristics, the feature type, and the object presentation

![Button as seen in three different lighting situations](image)
Ambient light is seldom used as light source for machine vision because of its variability.

Usually, the application is covered with a shroud to guarantee constant light.
- Assume a shroud is needed until the opposite is proven
- As an exception, controlled ambient light can be used as part of the vision application
2. RING LIGHT

- **The ring light principle**
  - Ring illumination on axis with camera
  - High intensity $\rightarrow$ short exposure times
  - Well-suited for easy and high speed applications

A ring light produces direkt illumination
2. DARKFIELD ILLUMINATION

- **The darkfield principle**
  - Low-angle light
  - Enhances edges for pattern recognition and scratch detection
  - Well-suited for inspecting sharp edges and very small 3D features on flat surfaces
The backlight principle
- Light from behind the object
- Enhances the object’s silhouette
- Well-suited for inspecting an object’s contours, for example shape or dimensions
2. ON-AXIS-ILLUMINATION

- The on-axis (co-axial) principle
  - The light is parallel to the optical axis, thanks to a semi-transparent mirror
  - Enhances contrasts between flat and sloped areas
  - Well-suited for inspecting the inside of hollow objects and small 3D features on flat surfaces

An on-axis light produces the silhouette

Ambient light

On-axis illumination
2. DOME ILLUMINATION

- **The dome principle**
  - The light is very diffuse thanks to an internal diffusor
  - Enhances true contrast and suppresses disturbing reflections in shiny surfaces
  - Well-suited for inspecting shiny objects

A dome light produces very diffuse light
2. SPOT AND BAR LIGHT ILLUMINATION

- **Spot and bar light principle**
  - Large freedom of geometry for targeted illumination
  - Which features are enhanced depends on the chosen geometry
  - Well-suited for low-cost (few LEDs), simple tasks

A spot light is enough to illuminate the critical features (weld spots, automotive)

A spot or bar light can illuminate in many ways thanks to its flexible mounting
2. AVOID HOT SPOTS > TILT THE CAMERA

- Glossy (shiny) materials reflect direct light sources → hot spots
- Tilt the camera to deflect the hot spots away from the lens

Note: Tilting → perspective problems when
- High accuracy is needed
- The object can rotate 360°
2. AVOID HOT SPOTS > DIFFUSE LIGHT

- If tilting the camera is no option
  - Use diffuse light to avoid direct reflections

Ring light gives direct light and hot spots

Inspector with built-in dome gives diffuse light

Hot spot

Even illumination
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2. OPTICAL FILTERS

- **Use filters to enhance contrast and suppress ambient light**
  - Available in different colors
  - Depending on type, either mount on lens or between lens and camera
  - Filters reduce intensity → longer exposure time needed → increased motion blur

Filters for Inspector

Filters for IVC-2D

Blue light + (optionally) blue filter maximizes contrast!
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3. INSPECTION, POSITIONING, MEASUREMENT, READING

- Precense detection of datcode
- Roboter guidance
- Barcode & OCR reading
- Solar waver alignment
## INDUSTRIAL IMAGE PROCESSING 2D & 3D

### 3. APPLICATION

<table>
<thead>
<tr>
<th>Nahrungsmittel</th>
<th>Getränke</th>
<th>Konsumgüter</th>
<th>Pharma</th>
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### INDUSTRIAL IMAGE PROCESSING 2D & 3D

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## INDUSTRIAL IMAGE PROCESSING 2D & 3D

### 3. VISION PORTFOLIO - 2D

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<tr>
<td>- Lector62x/63x/64x/65x (Barcodereading - Matrix)</td>
<td>- InspectorP63x (Vision - Matrix)</td>
<td>- Midi-Cam (Vision - Matrix)</td>
</tr>
<tr>
<td>- ICR88x /89x (Barcodereading - Line)</td>
<td>- InspectorP64x (Vision - Matrix)</td>
<td>- PicoCam (Vision - Matrix)</td>
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<tr>
<td>- Inspector (Vision - Matrix)</td>
<td>- InspectorP65x (Vision - Matrix)</td>
<td>- SIM4000 (Controller)</td>
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<td>- InspectorP (configurabel) (Vision - Matrix)</td>
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**Note:** The image includes visual representations of the sensors and cameras mentioned in the text.
### 4. 3 DIFFERENT TECHNOLOGIES - TRIANGULATION

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<th>TRIANGULATION</th>
<th>TIME OF FLIGHT</th>
<th>STEREO</th>
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<td><strong>Triangulation ratio between</strong></td>
<td><strong>Based on</strong></td>
<td><strong>Binocural principle</strong></td>
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<td>- laser line</td>
<td>- time, the light needs to „fly“ from the sensor</td>
<td>- two cameras</td>
</tr>
<tr>
<td>- camera</td>
<td>- speed of light</td>
<td>- passive system</td>
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<tr>
<td>- object height</td>
<td>- optical properties</td>
<td></td>
</tr>
<tr>
<td><strong>Range:</strong> ≤ 1,5 m</td>
<td><strong>Range:</strong> ≤ 7.2 m</td>
<td><strong>Range:</strong> ≤ 5 m</td>
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<tr>
<td><strong>Resolution:</strong> ≥ 0.05 mm</td>
<td><strong>Repeatability:</strong> ≤ 30 mm</td>
<td><strong>Repeatability:</strong> ≤ 1 mm</td>
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</table>
4. TRIANGULATION - 2 DIMENSIONAL MEASUREMENT

- **Triangulation**
  - Height information by triangulation ratio

  \[ \Rightarrow \text{3D information} \]

- **Movement needed!**
- **Active system \(\Rightarrow\) light is sent out**
  - Special conditions for scene illumination

- **Functional principle**
  - A laser line is projected onto the object being measured
  - The reflection is mapped onto a light-sensitive element (2D camera imager)
  - Based on the position of the mapped light spots and the known geometry of the sensor optics, the height profile is determined
Evaluation possibilities:

- Single height profile analysis
  => Profiling

- Multiple profiles calculated to a 3D image
  => 3D evaluation
4. 3D EVALUATION

- Working principle
  - A laser line is projected on the object
  - Individual height profile (laser displacement) is recorded by the camera (angled view)
  - Movement → multiple contour profiles are collected → put together to a 3D image
  - Encoder pulses → control equal profile distances → no distortion
  - Photoelectric sensor → starts the image recording

- 3D image = Collection of height profiles
### Image resolution
- Image length (y) and width (x) in pixels
- Height resolution in mm

### Object resolution
- Like a 2D setup with perspective, x and y resolution can be different
- **X resolution** (mm/pix) determined by the pixel width and optics
- **Y resolution** (mm/pix) determined by the scan rate
- **Z resolution** (mm) determined by the geometry and sensor algorithms

### For systems with flexible lens and geometry (Ranger), 3D resolution is normally application specific → no common specification in data sheet possible
4. TRIANGULATION - OCCLUSION AND MISSING DATA

- **Camera occlusion / shadowing**
  - The laser line is hidden from the camera behind object features

- **Laser occlusion**
  - The laser cannot illuminate parts behind object features

- **Missing data**
  - Parts of the image contain no information because of occlusion or underexposure
High-speed 3D and color in one camera

- Color = combination of three separate lines with red, green and blue filters on the sensor

- Color can be very useful in addition to 3D, grayscale and scatter

- Creation of a colored 3D image is possible

Example: M&M’s separation
## 4. TIME OF FLIGHT

### TRIANGULATION

- Triangulation ratio between
  - laser line
  - camera
  - object height

  - Range: ≤ 1.5 m
  - Resolution: ≥ 0.05 mm

### TIME OF FLIGHT

- Based on
  - time, the light needs to „fly“ from the sensor
  - speed of light
  - optical properties

  - Range: ≤ 7.2 m
  - Repeatability: ≤ 30 mm

### STEREO

- Binocular principle
  - two cameras
  - passive system

  - Range: ≤ 5m
  - Repeatability: ≤ 1 mm
Modulated light is sent out continuously (“light waves”) – LEDs - no laser => illuminated area

- The reflected light wave is evaluated per pixel continuously
- The phase shift between sent wave and the received wave per pixel is measured
- The distance is calculated per pixel based on the phase shift
Modulated light is sent out continuously ("light waves")

LED array => 3D illumination

The light is reflected back to the camera

The reflected light wave is evaluated per pixel at imager continuously

The phase shift between sent wave and the received wave per pixel is measured

The distance is calculated per pixel based on the phase shift
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4. TIME OF FLIGHT – PHASE CORRELATION – 3 DIMENSIONAL
### 4. STEREO

#### TRIANGULATION
- Triangulation ratio between
  - laser line
  - camera
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  - Range: ≤ 1.5 m
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- Binocular principle
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4. STEREO CAMERA

- Two 2D cameras with slightly different view angles
  - Comparable to human binocular vision
  → 3D information

- Snapshot camera – no movement needed!

- Passive system => no light is sent out
  - No special conditions for scene illumination
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4. STEREO CAMERA

- Two 2D cameras with slightly different view angles

⇒ Overlay of both images
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4. STEREO CAMERA

- Two 2D cameras with slightly different view angles

⇒ Overlay of both images
⇒ Depth calculation
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4. STEREO CAMERA

<table>
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<th>TWO 2D IMAGES</th>
<th>OVERLAY</th>
<th>DEPTH CALCULATION</th>
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![Diagram showing the process of two 2D images being overlaid to calculate depth.](image-url)
## INDUSTRIAL IMAGE PROCESSING 2D & 3D
### 5. APPLICATION 2D OR 3D?

- **When to use 2D?**
  - Information is in contrast difference
    - Printings
    - Surfaces
    - ...
- **When to use 3D?**
  - Information is in height difference
    - Sizes (Width, heights, volume, ...)
    - Shape
    - ...
- **Examples**
  - 1. Which pin is too low?
  - 2. Which steel part is on top?
  - 3. Which wrapper has misaligned text?
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5. APPLICATION – 3D

- **Application**
  - Inspect chocolate praline for completeness and correct orientation before final packaging
  - Color independent – just height based
  - Digital output for good / bad classification

- **Product**
  - TriSpector 1000

- **Application**
  - Checking brake pads using 3D vision
  - The sensor evaluates surfaces, heights, distances, angles, ...

- **Product**
  - IVC-3D

- **Application**
  - Measure the height and load of palettes in standstill applications
  - Used for automated loading and unloading

- **Product**
  - 3visor-T

- **Application**
  - 360° measurement of logs
  - Automatic optimization of board cutting

- **Product**
  - Ruler
5. APPLICATION – 3D

**PLB**

Part Localization in Bins for Robotic part handling (Griff in die Kiste)

**PLR**

Part Localization in Racks (Teile Lokalisieren in Racks)

**Straw**

Straw & Cap Detector

**ConVer**

Content Verification for flat Packs

**CoPlan**

Coplanarity Analyzer
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5. PRODUCTS FOR 3D VISION APPLICATIONS

2D VISION

3D VISION
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<td><strong>TriSpectorP1000</strong></td>
<td><strong>Ranger / Ranger3</strong></td>
</tr>
<tr>
<td>(Vision - Triangulation)</td>
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<tr>
<td><strong>Visionary</strong></td>
<td><strong>IVC-3D</strong></td>
<td><strong>Ruler / ScanningRuler</strong></td>
</tr>
<tr>
<td>(Vision - TOF)</td>
<td>(Vision - Triangulation)</td>
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<tr>
<td><strong>PLB520</strong></td>
<td></td>
<td><strong>Visionary</strong></td>
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<tr>
<td>(Vision - Stereo)</td>
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<td>(Vision - TOF)</td>
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<td><strong>SIM4000</strong></td>
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<td>(Controller)</td>
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THANKS FOR YOUR ATTENTION!

Renè Klausrigler
Productmanagement „Identification & Measuring“

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