MSTVision

72. Heidelberger Bildverarbeitungsforum

Beleuchtung, Optikkomponenten und Computational Imaging

High Speed Photometric Stereo

Michael Stelzl

02.07.2019

Agenda

Introduction

Solutions

High Speed

Company profile

Services:

- Development of algorithms/scripts using the HALCON software library from MVTec
- Development of FPGA solutions using the VISUAL APPLETS developer environment from Silicon Software
- Feasibility and concept studies including test set-ups adapted to customer requirements
- Development or training workshops at customer's site or in our facilities
  (e.g. inspection concepts, roadmap meetings with the R&D team, HALCON, line scan cameras …)
- Supporting all phases of R&D and procurement projects including acceptance tests
  and performance evaluation of inspection systems

MVTec Software GmbH CERTIFIED INTEGRATION PARTNER

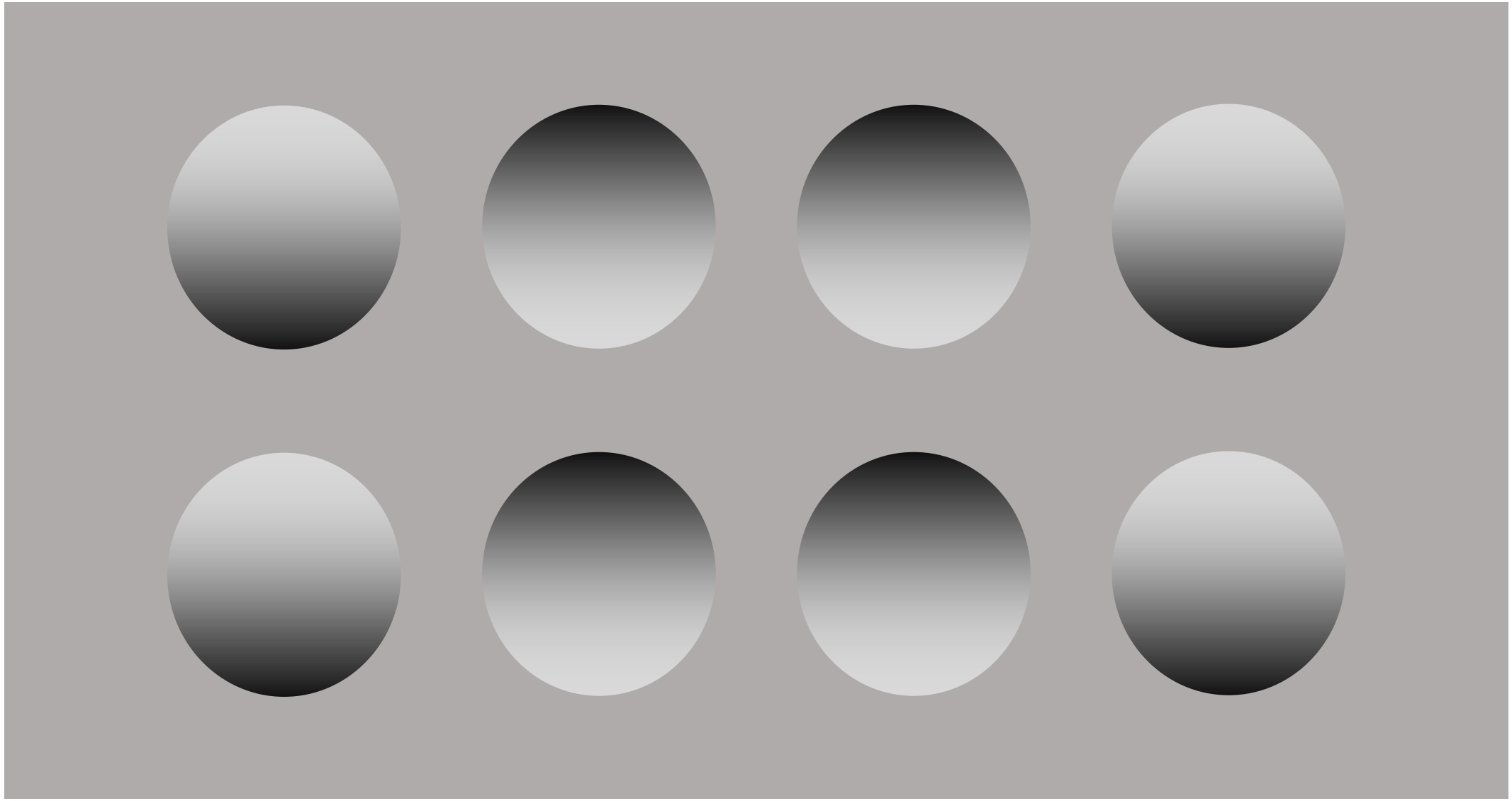
VACC COMPETENCE CENTER VADC DESIGN CENTER

GMA FA 8.12 => VDI/VDE/ VDMA 2632

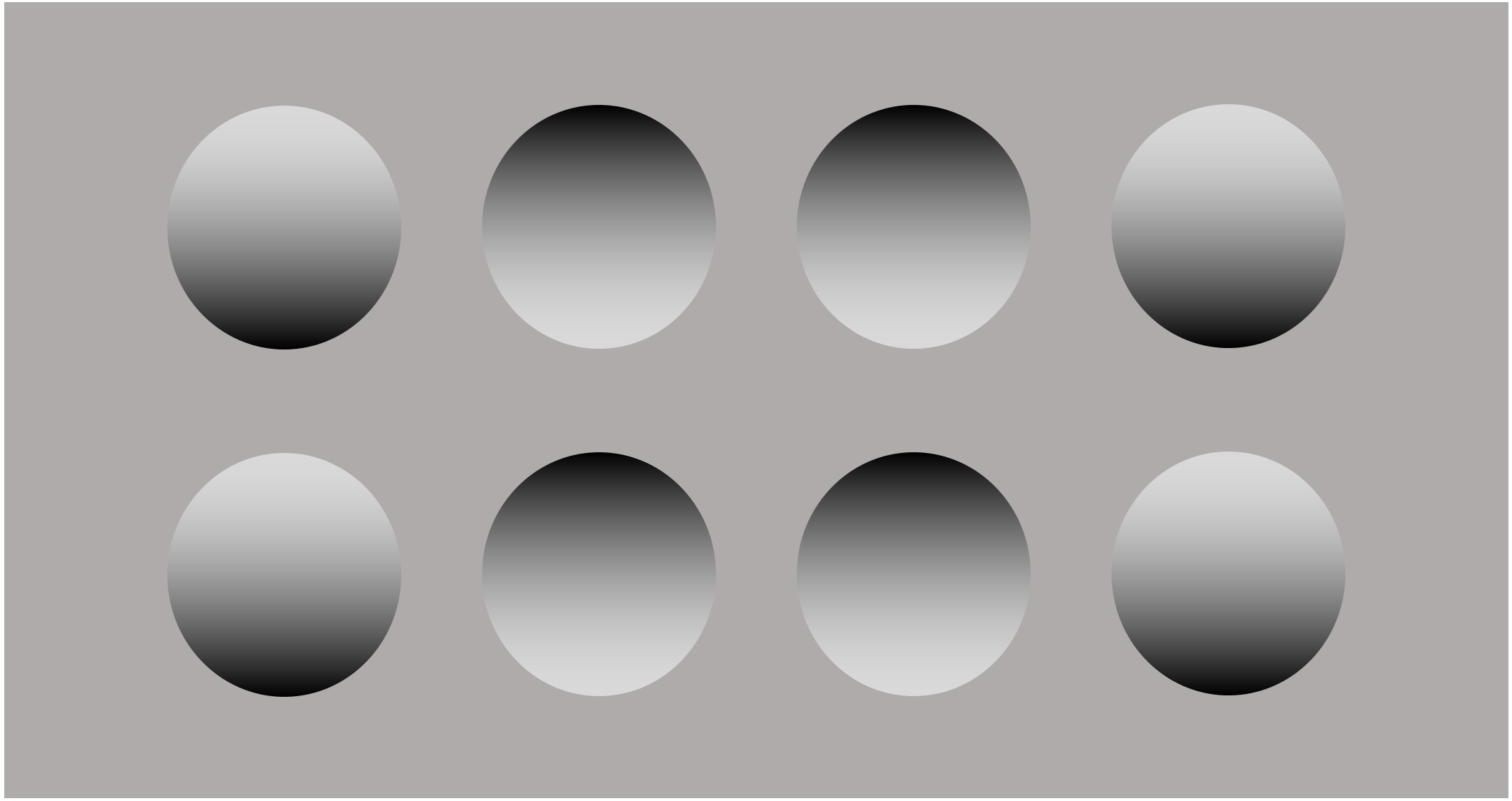
Solutions:

- Technology modules for high speed sorting applications
- MultiChannel technology
- Development of stand alone systems or sub modules
- Several hardware components

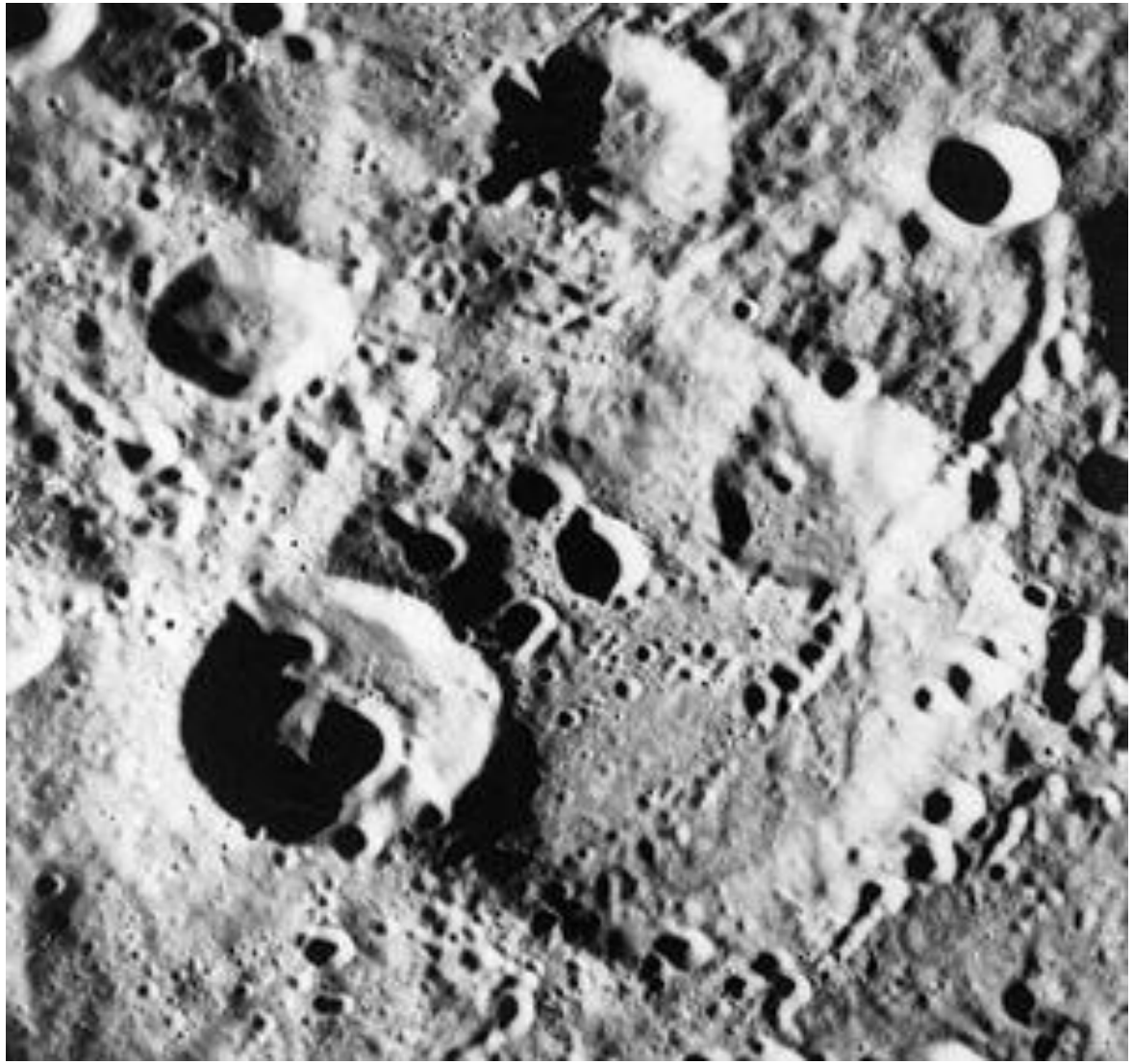
Which circles are bumps and which are dents?

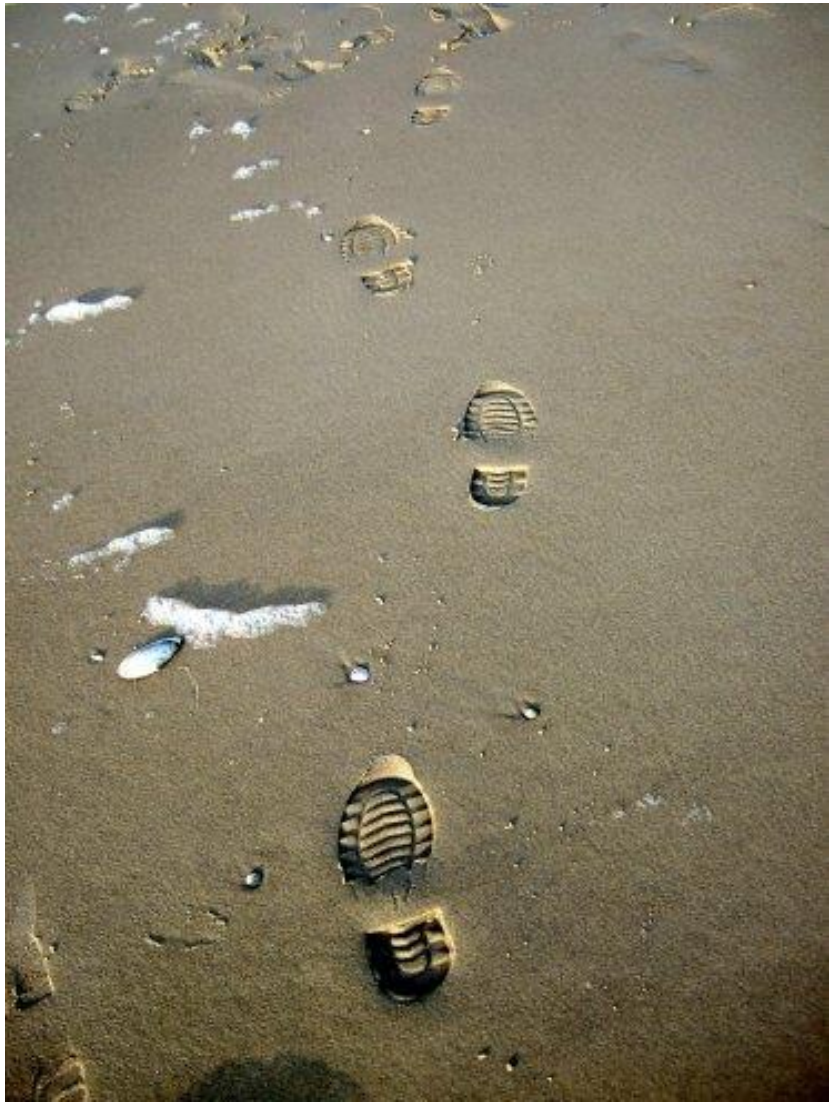


Which circles are bumps and which are dents?



Moon crater / footprints



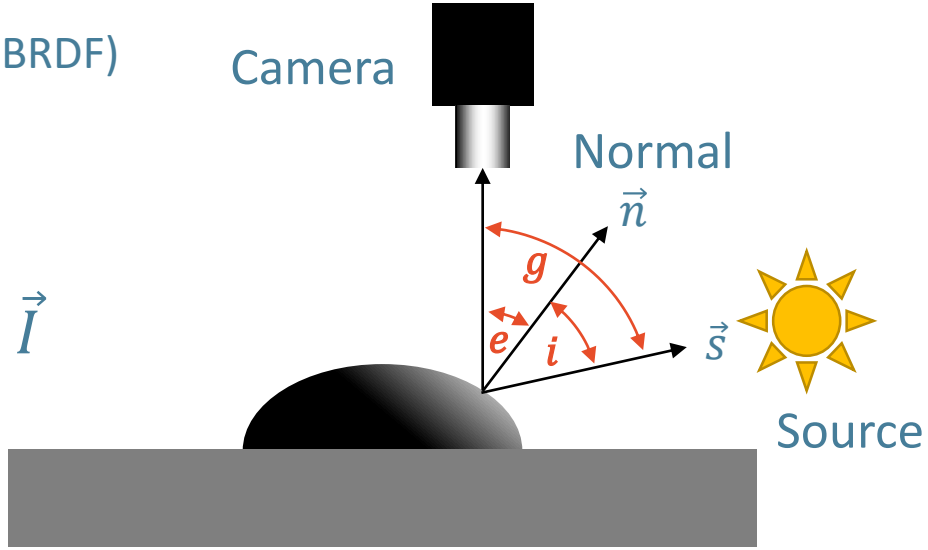


Theory behind Photometric Stereo

Woodham, R.J. 1980.
"Photometric method for determining surface orientation from multiple images"

Optical Engineerings 19, I, 139-144. See: https://www.cs.ubc.ca/~woodham/papers/Woodham80c.pdf

$\emptyset\ (i,e,g)=\rho\ \cos(i)$ $\emptyset$: Bidirectional reflectance distribution function (BRDF)
ρ: Albedo



$I\ (x,y)=\rho*\vec{s}*\vec{n}$

$I_1=\rho*\overrightarrow{s_1}*\vec{n}$
$I_2=\rho*\overrightarrow{s_2}*\vec{n}$
$I_3=\rho*\overrightarrow{s_3}*\vec{n}$

$\vec{I}=\rho*S*\vec{n}$

$\rho*\vec{n} = S^{-1} * \vec{I}$

$\rho = \left|S^{-1} * \vec{I}\right|$

$\vec{n} = \frac{1}{\rho} * S^{-1} * \vec{I}$

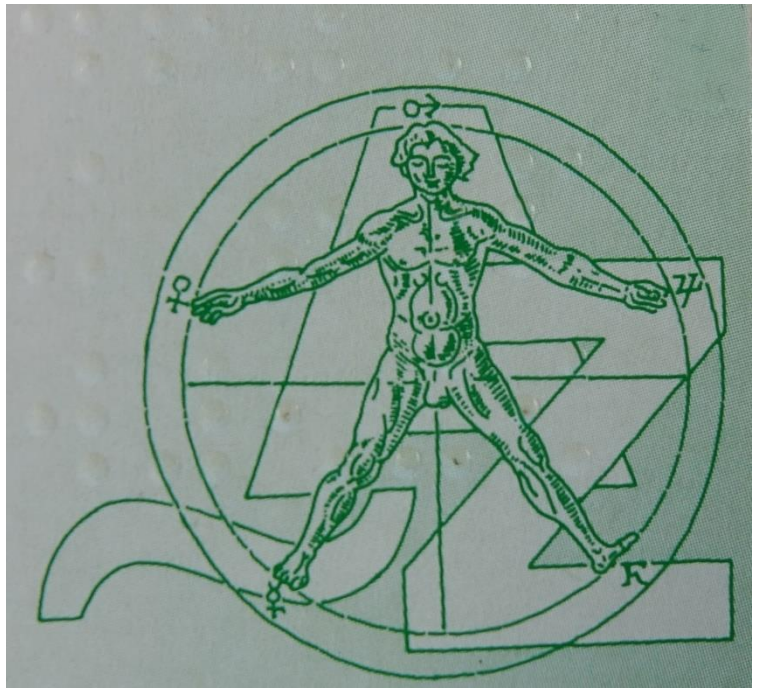
Lambertian radiator:
The radiant intensity observed is proportional to the cosine of the angle i between the illuminating source and the surface normal, intensity observed does not depend on viewing direction

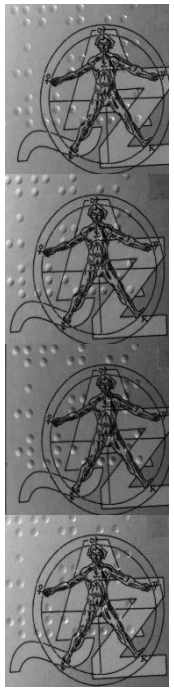
Theory behind Photometric Stereo

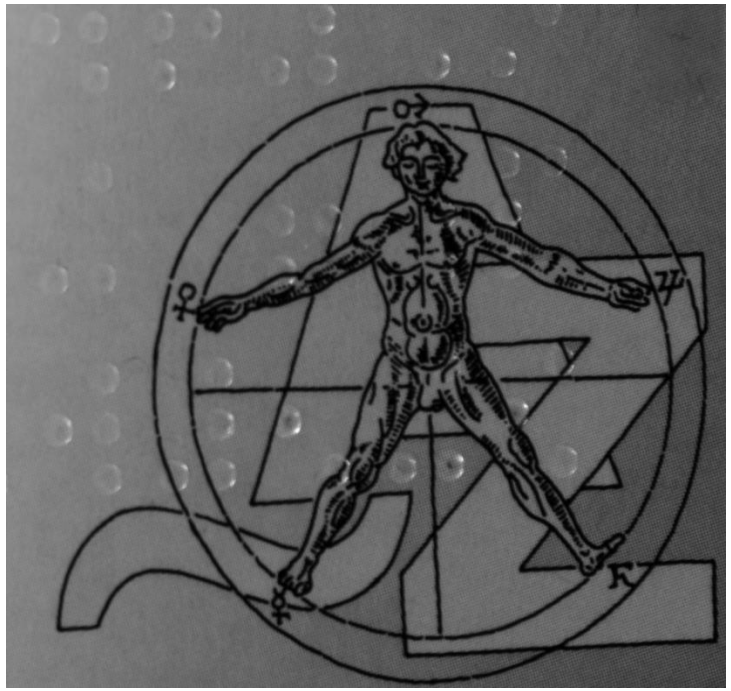
- 3 images needed to separate albedo (texture) and surface slope (curvature)
- Most systems use 4 images (or more)
- Assumes Lambertian radiator => does not work for specular surfaces!
- Assumes telecentric lens and telecentric illumination

Albedo (Texture) | Curvature | Surface slope X | Surface slope Y

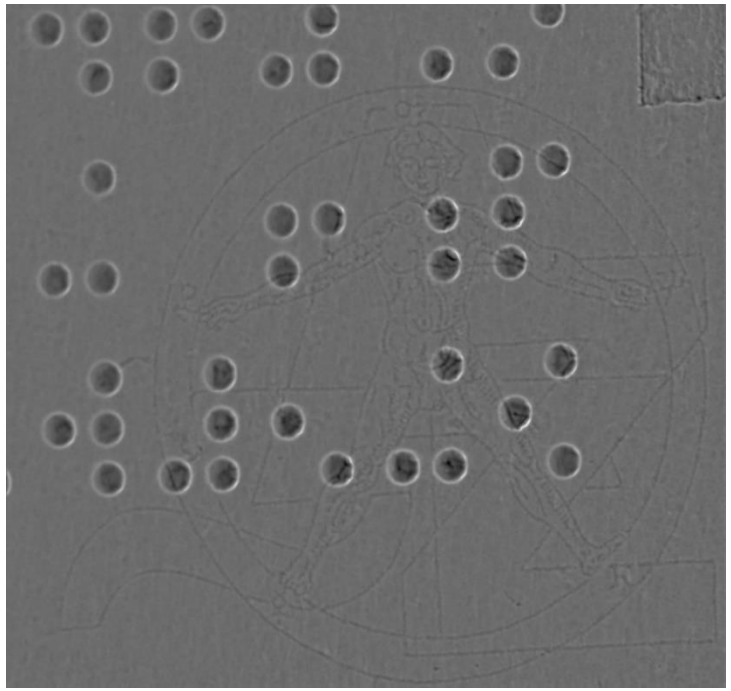
Example I: Embossed printing (Braille)





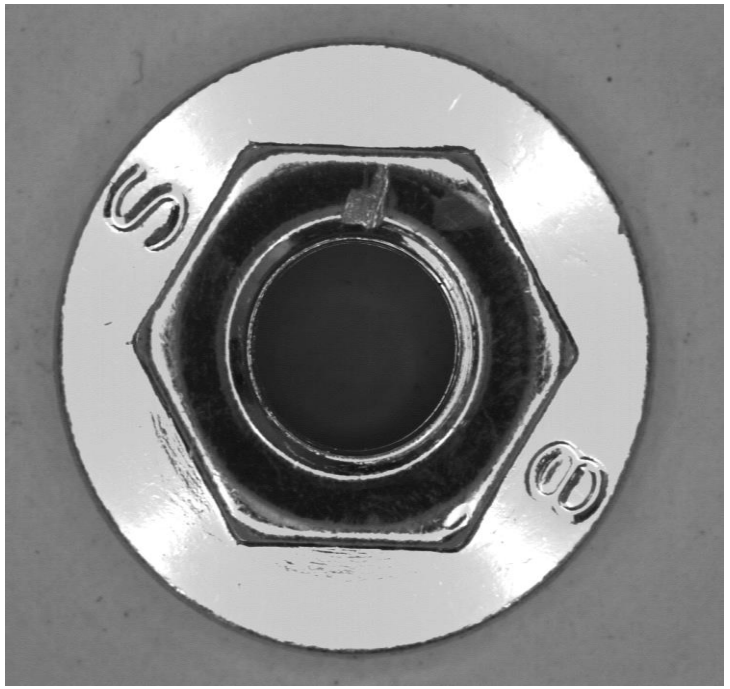


Albedo image
(Texture)

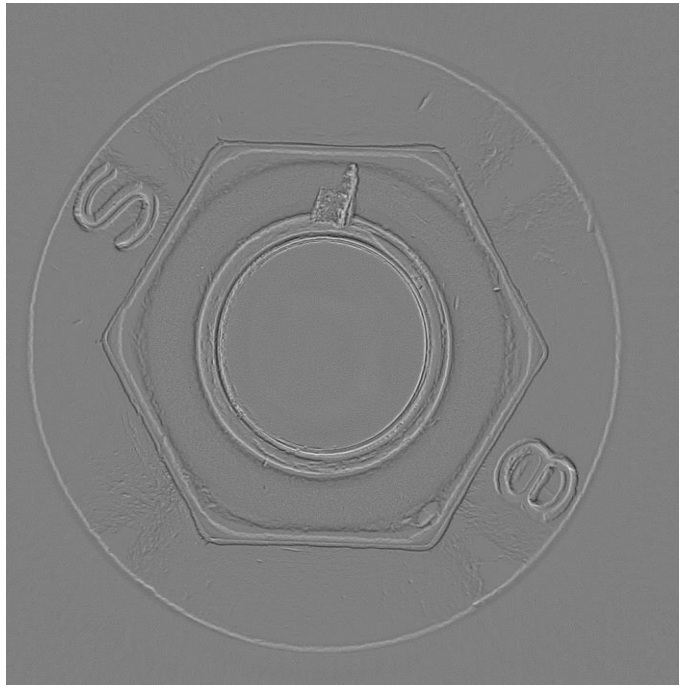


Mean curvature

Example II: Metal parts



Albedo image
(Texture)



Mean curvature

Agenda

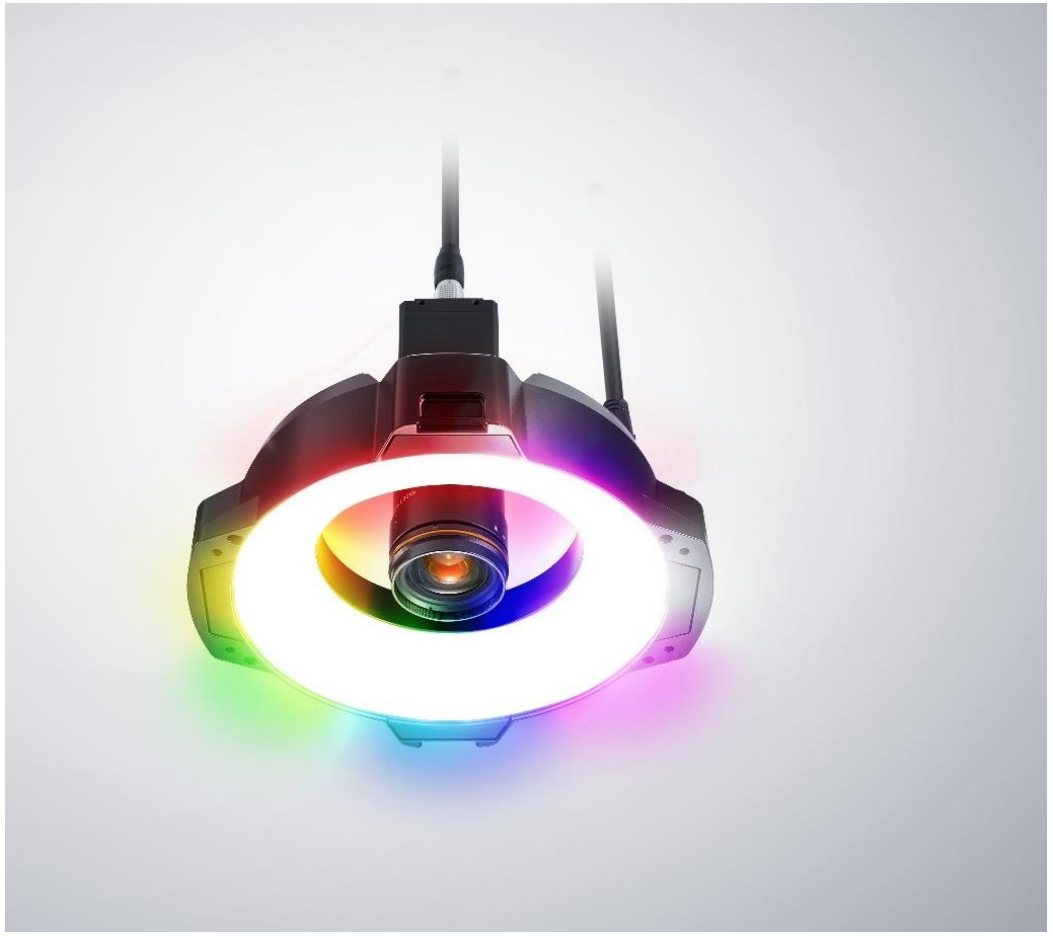
Introduction

Solutions

High Speed

Ready to use turnkey solutions

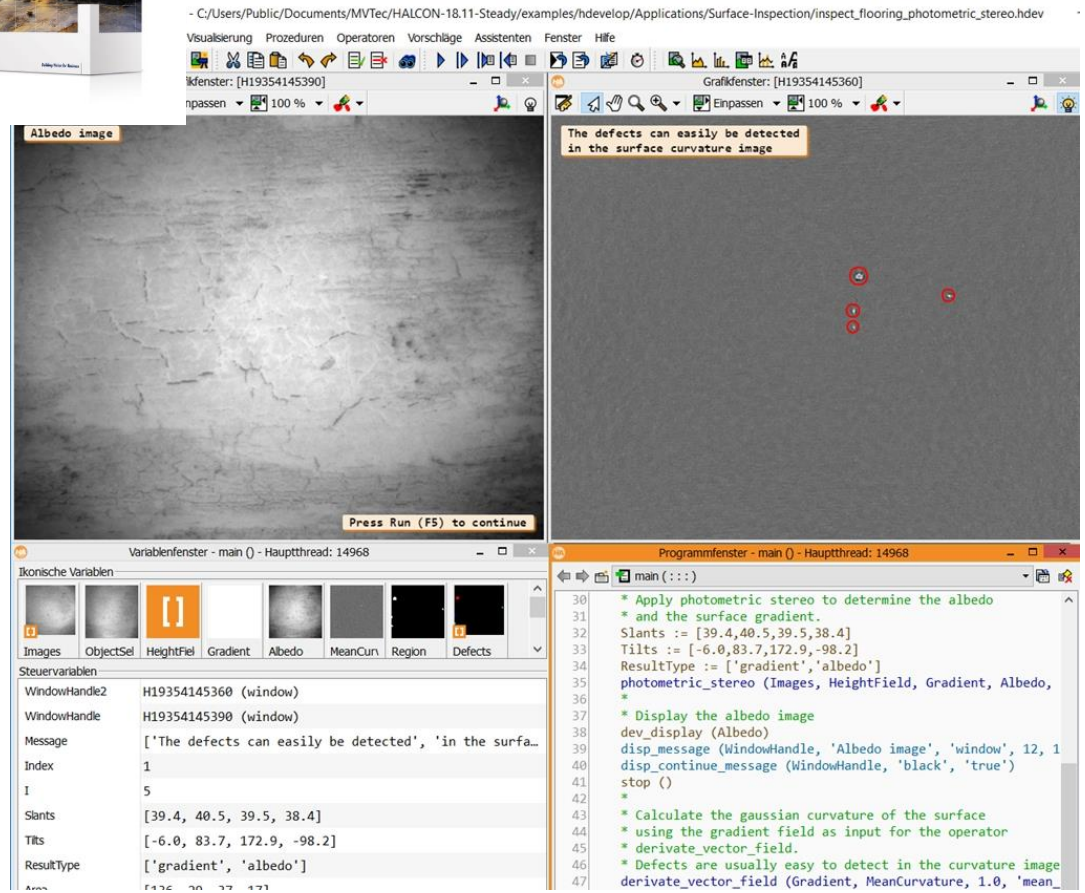
Source:
SAC Sirius Advanced Cybernetics GmbH



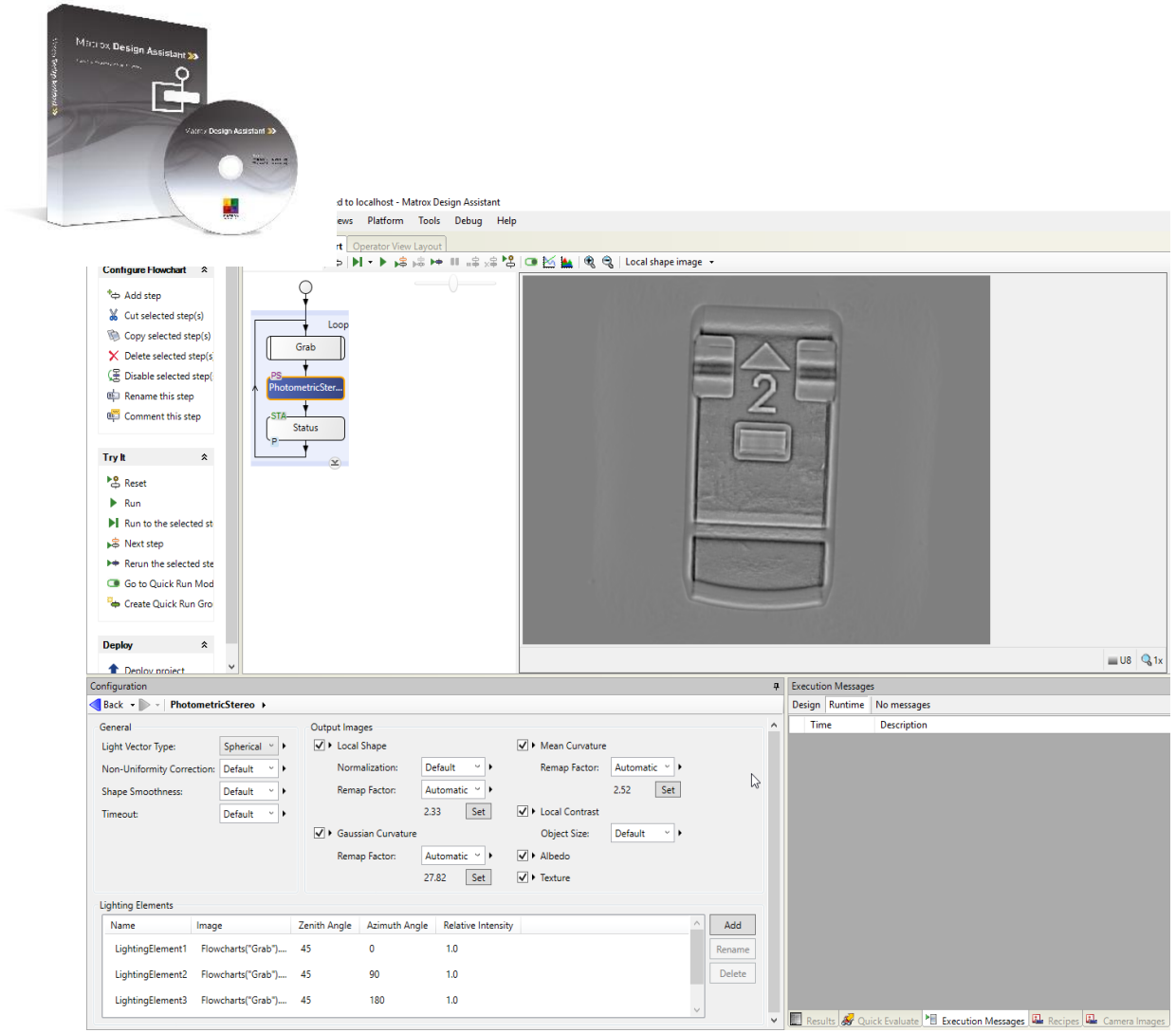
Source:
KEYENCE DEUTSCHLAND GmbH

Hint => Check patents

Commercial software libraries



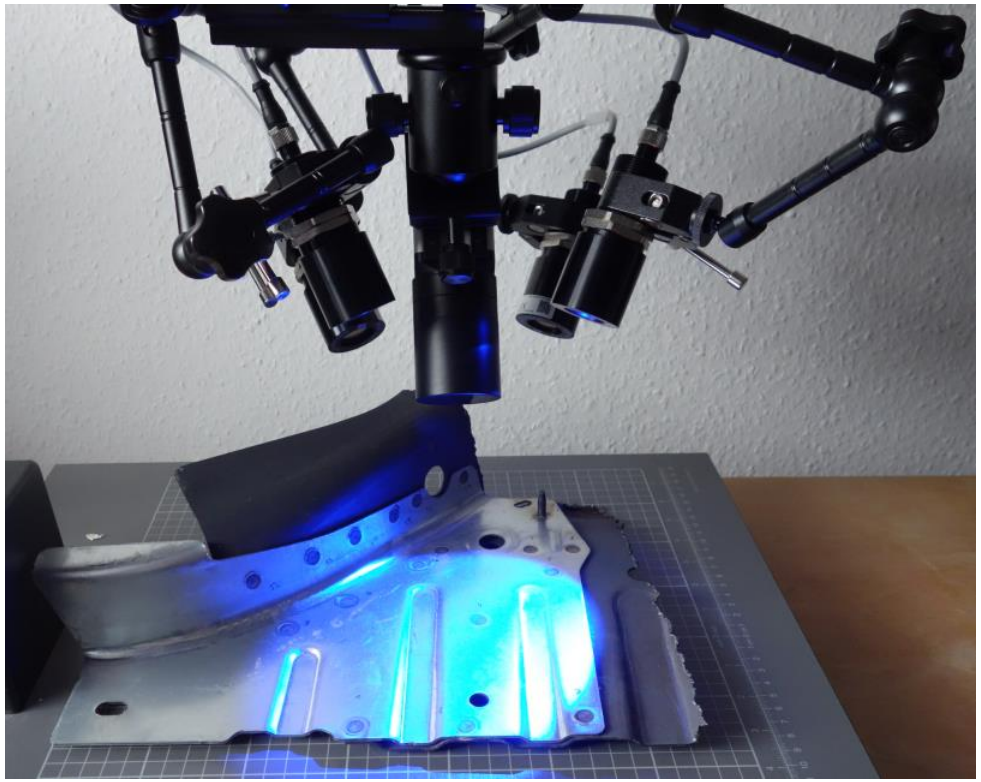
Source: MVTec Software GmbH



Copyright: RAUSCHER GmbH und Matrox Imaging

Camera <-> Spots <-> IO interface

Quelle: https://www.wago.com/de/automatisierungstechnik/sps-entdecken/pfc100



2 MPixel image / 200ms => 10MPixel/s
(bottleneck: synchronization)

Lighting components with added features

COMPUTATIONAL ILLUMINATION HARDWARE

Computational Imaging

LSS-2404 Programmable Controller

Both 4 and 12 channel versions

HPR2 Quad Ring Light

- Multi-segment lights
- Multi-spectral lights
- Multiple lights with breakout cables

Light + Camera + Bracket

Source: https://www.stemmer-imaging.com/media/uploads/ccs/CC/CCS-EN-Computational-Imaging-for-Machine-Vision.pdf

CCS

Smart Vision Lights LLM

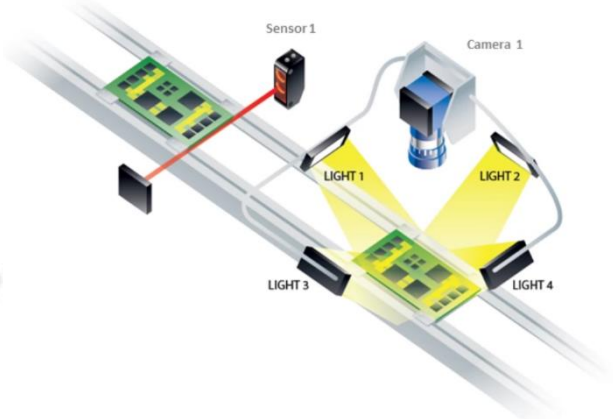
NEU

LED Light Manager

Der **programmierbare LED Light Manager (LLM)** von **Smart Vision Lights** ermöglicht die Beleuchtungssteuerung für industrielle Bildverarbeitungsanwendungen mit mehreren Beleuchtungen, einschließlich **photometrischer 3D- und Multispektralinspektion**. Der LLM kann bis zu **vier separate Beleuchtungen** oder bis zu vier einzelne Quadranten bzw. Kanäle innerhalb eines integrierten photometrischen oder multispektralen Ringlichts ansteuern. Jedes LLM-Programm kann **bis zu sechs Sequenzen mit bis zu vier Beleuchtungen** oder vier Ringlicht-Quadranten enthalten, die auf "Ein", "Aus", eine beliebige Intensitätsstufe dazwischen oder sogar auf OverDrive-Blitzbetrieb für höhere Lichtstärke in kurzen Impulsen eingestellt werden können.

Mit dem LLM lassen sich mehrere Beleuchtungen unabhängig voneinander steuern, selbst wenn diese im **Dauerbetrieb, Multi-Drive- oder OverDrive-Modus** betrieben werden. Die Sequenzen und Intensitätsstufen werden über eine **intuitive, browserbasierte Benutzeroberfläche** programmiert.

Source: https://www.stemmer-imaging.com/de-de/produkte/serie/smart-vision-lights-llm/

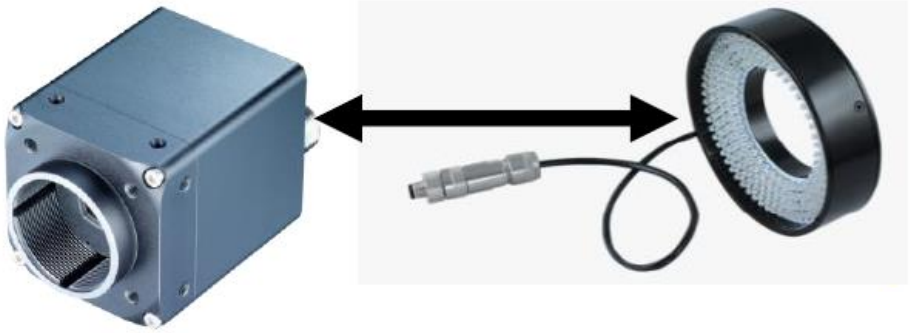


Source: https://www.stemmer-imaging.com/de-de/produkte/serie/gardasoft-cc320/

2-5 MPixel / 50-100ms => 20-100MPixel/s (bottleneck: GigE bandwidth)
Risk of artefacts due to moving sample!

Cameras with 4 powerful outputs and sequencer mode

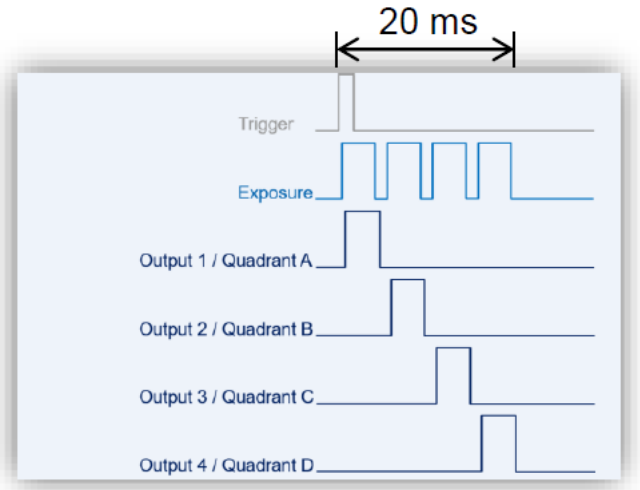
CX.I cameras (VCXG.I) Baumer



UEXT: 12 … 48 V DC
IOUT: max. 2500 mA

UEXT flash mode: 48 V DC
I max. flash mode: 880 mA

Source: https://www.genesi-elettronica.it/



External trigger starts Sequencer

Internal sequencer controls 4 image acquisitions

Output 1 controls illumination quadrant A

Output 2 controls illumination quadrant B

Output 3 controls illumination quadrant C

Output 4 controls illumination quadrant D

Source: http://vt.baumer.com/in-en/products/identification-image-processing/industrial-cameras/cx-series/

5 MPixel / 5ms => 1.000MPixel/s (bottleneck: GigE bandwidth, LED intensity and CPU!)

Agenda

Introduction

Solutions

High Speed

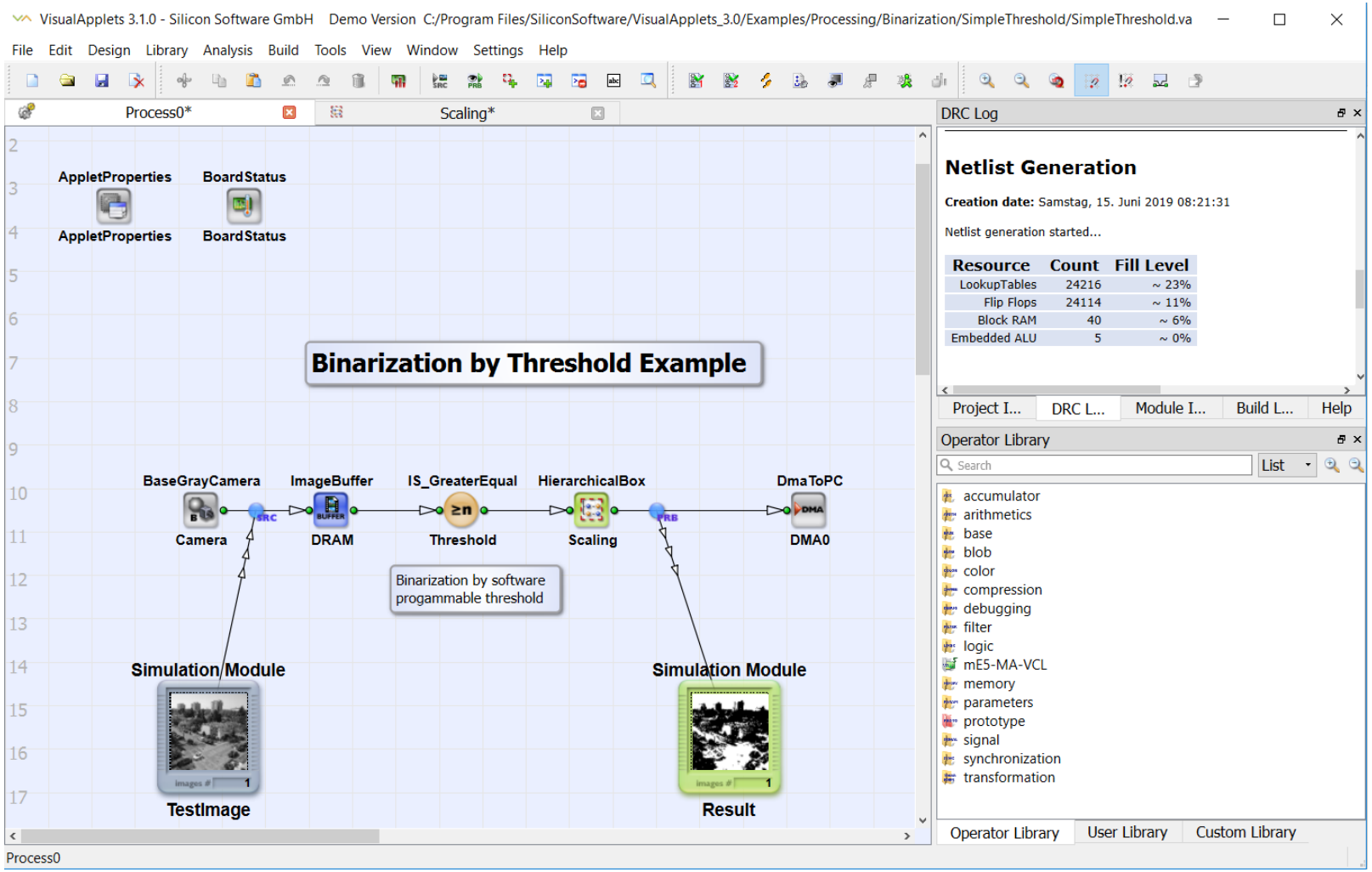
Graphical FPGA* programming

*See: https://en.wikipedia.org/wiki/Field-programmable_gate_array

VISUAL APPLETS

Graphical programming and development environment for the use of FPGA processors in imaging and machine vision.

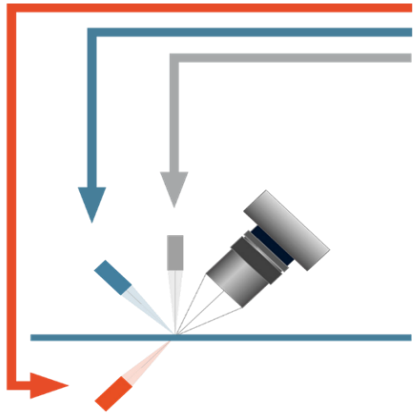
The strength of FPGAs is their ability to **process large volumes of data at high speeds through parallelization.**

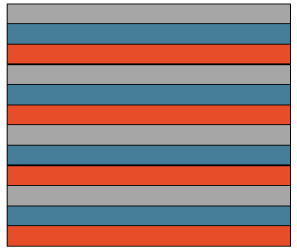


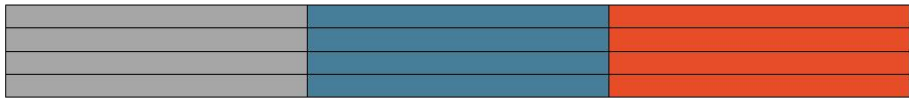
Source: https://silicon.software/products/visual-applets/

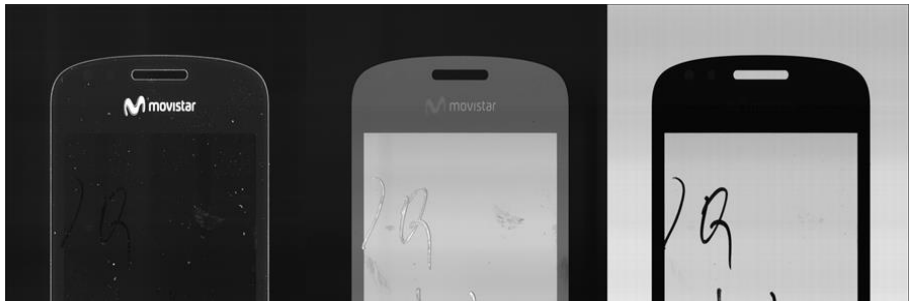
MultiChannel: Concept

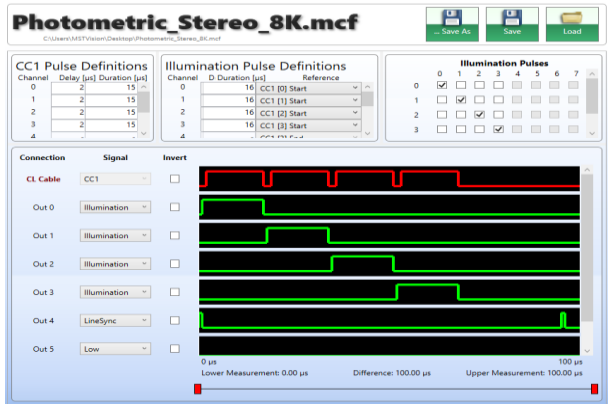
MultiChannel allows several lighting setups to be triggered on an alternating basis in combination with a synchronized camera exposure. The mixed flow of image data from the camera is rearranged within the frame grabber without CPU load.



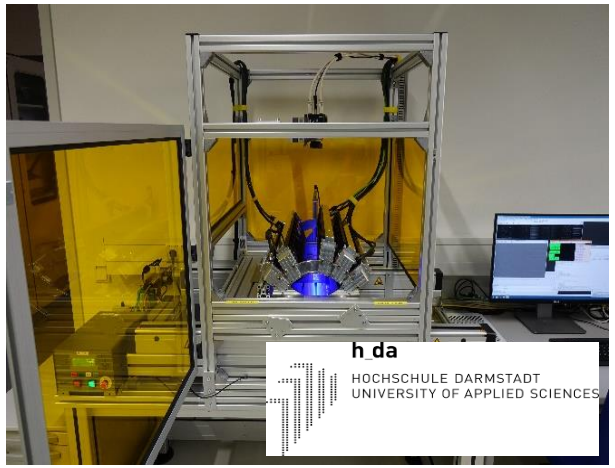








See: http://mtd-light.de/



Photometric Stereo: CPU based

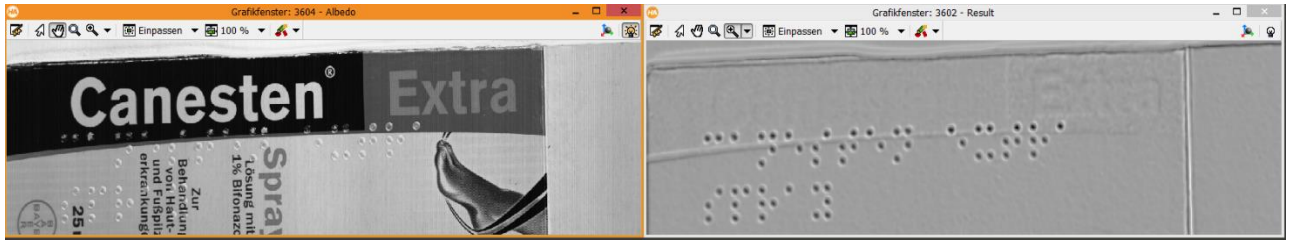
Programmfenster - main* () - Hauptthread: 6408

*main (: : :)

```
ChannelCount:=4
Tilts:=[-135,-45,135,45]
Slants:=[32,58,58,32]
open_framegrabber ('SiliconSoftware', 1, 1, 0, 0, 0, 0, 'interlaced', 8, 'gray', -1, 'false', 'MultiChannel_RadioMetricStereo.mcf', '1', 0, -1, AcqHandle)
grab_image (Image, AcqHandle)
get_image_pointer1 (Image, Pointer, Type, Width, Height)
gen_empty_obj (Images)
for ChannelIndex := 1 to ChannelCount by 1
    crop_rectangle1 (Image, ImageTemp, 0, Width*(ChannelIndex-1)/ChannelCount, Height, Width*(ChannelIndex)/ChannelCount)
    concat_obj (Images, ImageTemp, Images)
endfor
photometric_stereo (Images, HeightField, Gradient, Albedo, Slants, Tilts, 'all', 'poisson', [], [])
derivate_vector_field (Gradient, Result, 3, 'mean_curvature')
```

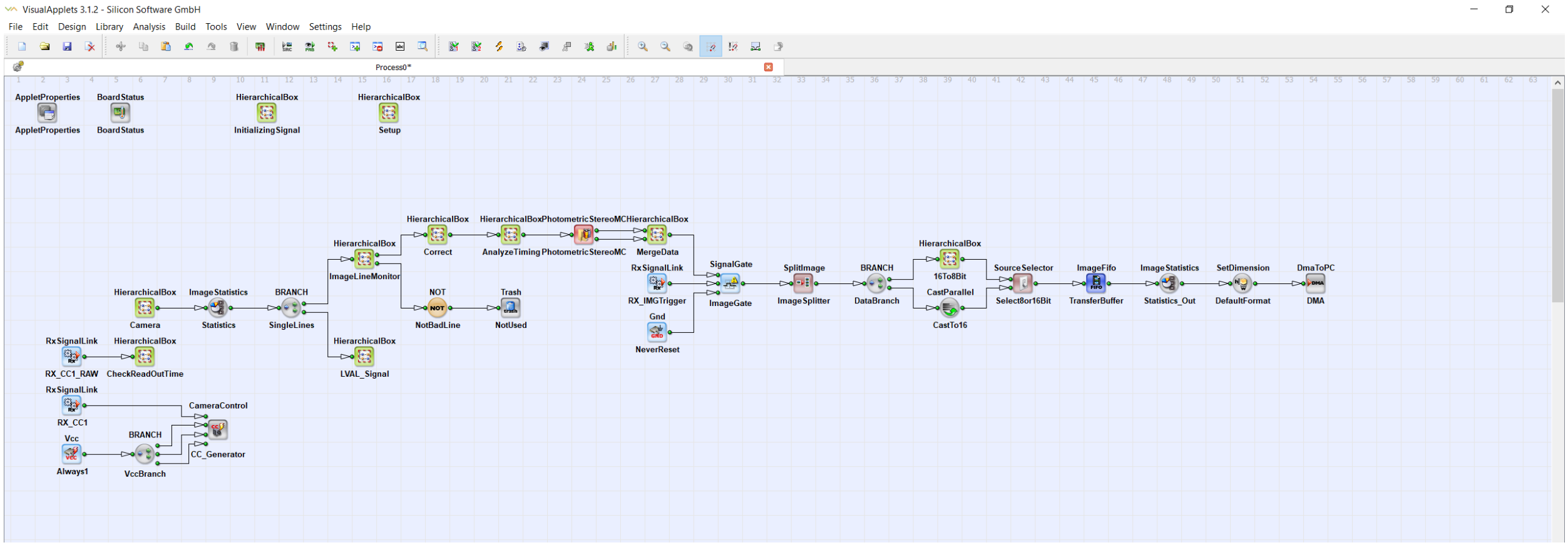
Just a few lines of HDevelop code are needed to:

- define the geometry
- open the framegrabber
- grab the image
- separate the channels
- calculate the Albedo and Curvature image



8K @ 100KHz => 800MPixel/s
(bottleneck: LED intensity, CL bandwidth and CPU!)

FPGA based Photometric Stereo



Band width & efficiency comparison

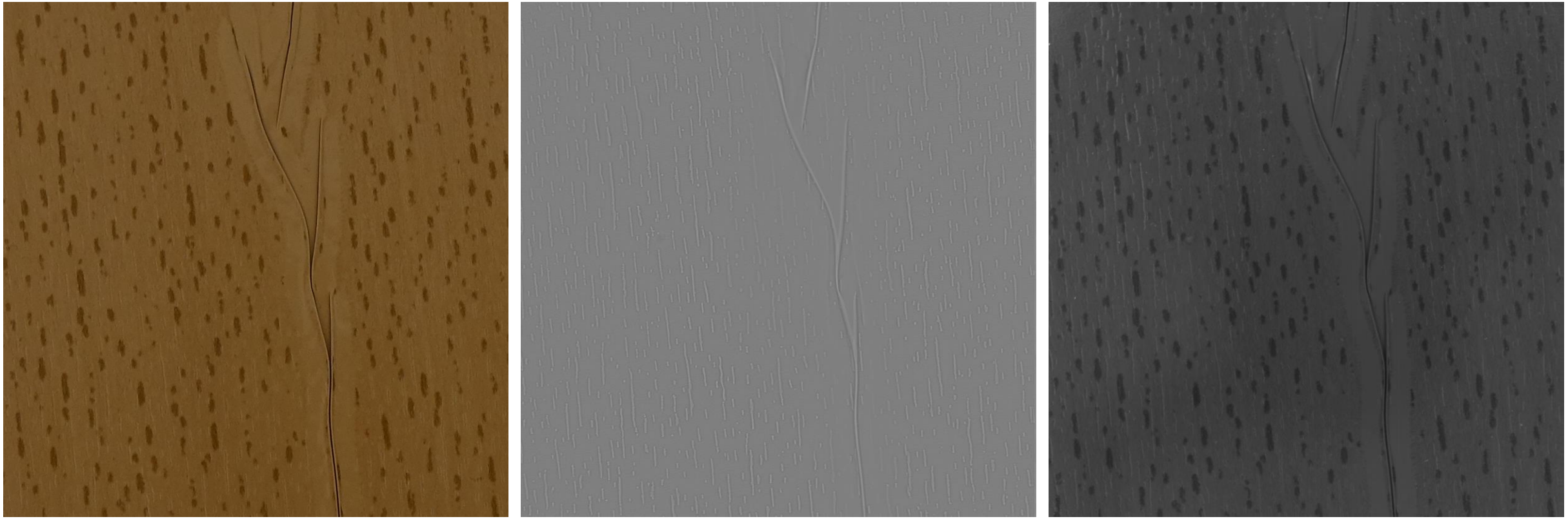
Hardware	Band width [MPixel/s]	„Efficiency" [MPixel/s/Watt]
CPU Intel© i5-8400 (65 Watt)	~220 (only CPU internal)	3
GPU AMD© RX580 (185 Watt)	-340 (only GPU internal)	2
Silicon Software microEnable 5 VCL (12Watt)	500 (theoretical)	42
Silicon Software microEnable 5 VCLx (16,8Watt)	1000 (theoretical)	60
Silicon Software microEnable 5 VCL e2v eliixa+ (CL Base) 8K @ 20KHz	~160 (within application)	13
Silicon Software microEnable 5 VCL (12Watt) Basler Racer (CL Medium) 6K @ 50KHz	~300 (within application)	26
Silicon Software microEnable 5 VCLx (16,8Watt) Basler Aca 2040 (CL Full) 4 MPixel @ 180Frames/s	~750 (within application)	45

FPGA based Photometric Stereo

- enables acquisition and calculation of
  - curvature
  - X/Y surface slope
  - texture
- at speeds never reached before – Bandwidth up to 755 MPixel / s
- without CPU load, no library needed
- with equal results to industry proven software solution (8 Bit images)
- implemented for matrix and line scan cameras
- enables continuous surface inspection at large inspection width using multiple line scan cameras
- combination with other illumination setups

- Future:
  - FPGA based BLOB analysis in curvature image
  - FPGA based CNN (deep learning)

New applications



courtesy of MTD GmbH

New approach enables continuous surface inspection with multiple cameras to check for “topography defects”

e.g. finish foil & decorative laminates, metal sheet production and more

Q&A