

72. Heidelberger Bildverarbeitungsforum

Beleuchtung, Optikkomponenten und Computational Imaging

High Speed Photometric Stereo

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02.07.2019

Introduction

Solutions

High Speed

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



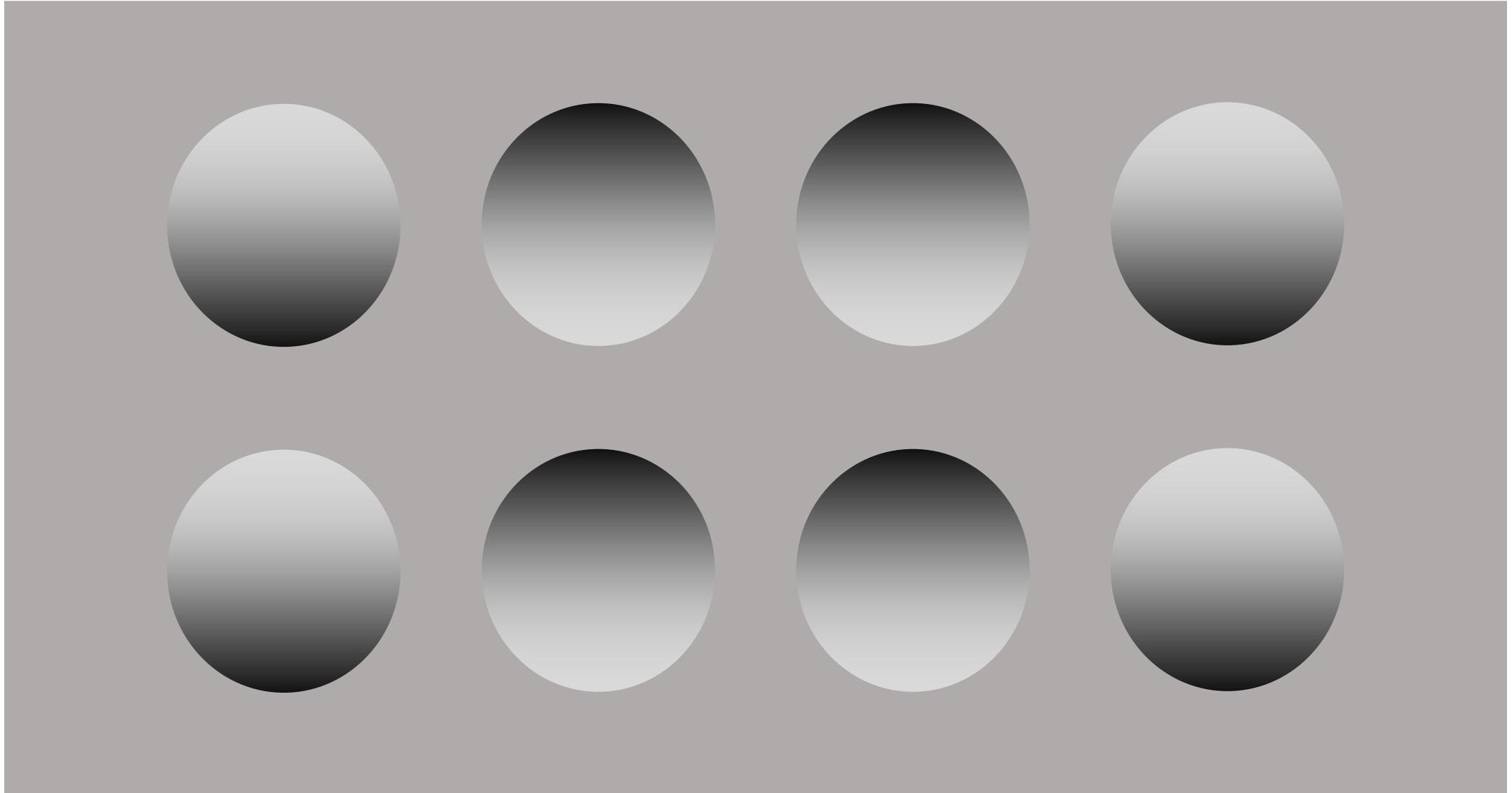
GMA FA 8.12 => VDI/VDE/VDMA 2632

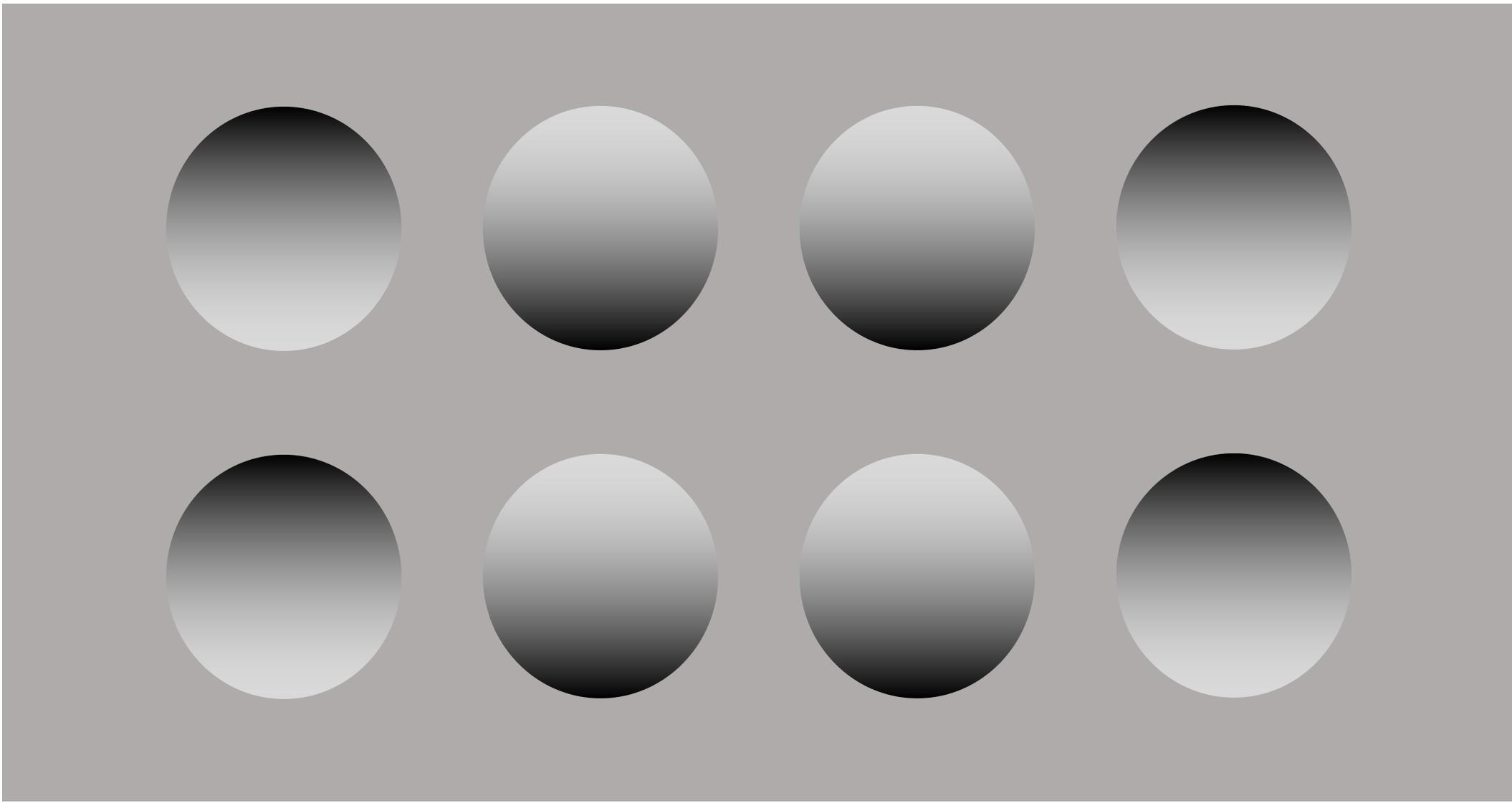
Solutions:

- 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?







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Woodham, R.J. 1980.

“Photometric method for determining surface orientation from multiple images”

Optical Engineerings 19, 1, 139-144. See: <https://www.cs.ubc.ca/~woodham/papers/Woodham80c.pdf>

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

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

$$I_1 = \rho * \vec{s}_1 * \vec{n}$$

$$I_2 = \rho * \vec{s}_2 * \vec{n}$$

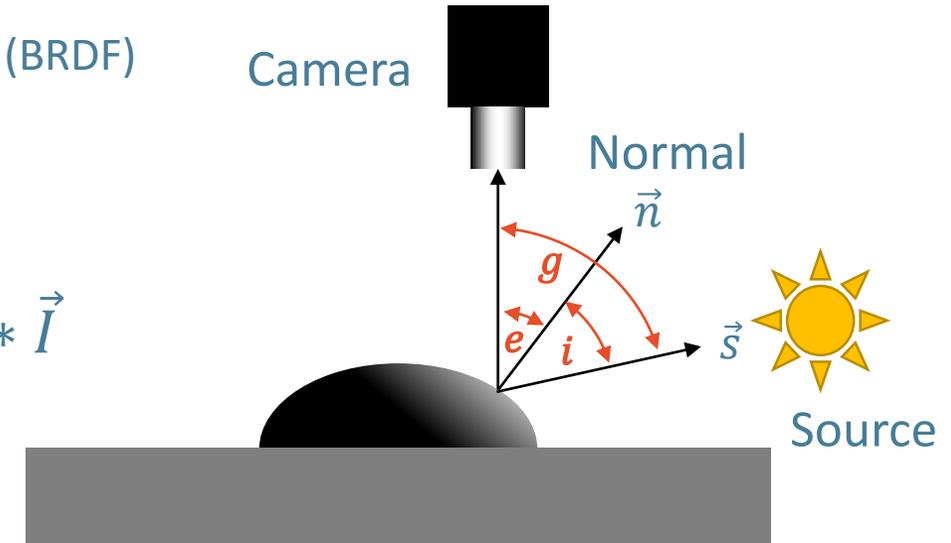
$$I_3 = \rho * \vec{s}_3 * \vec{n}$$

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

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

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

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

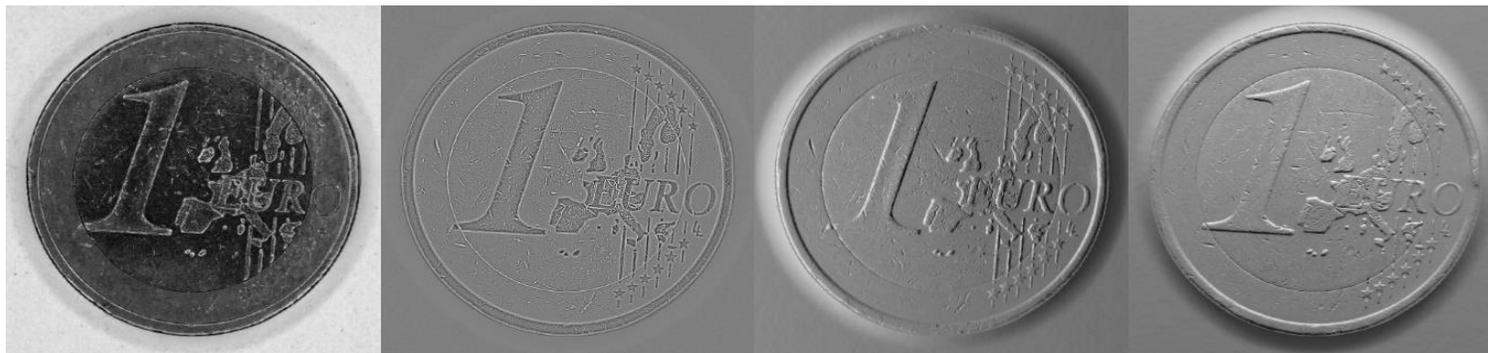


Lambertian radiator:

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



- 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

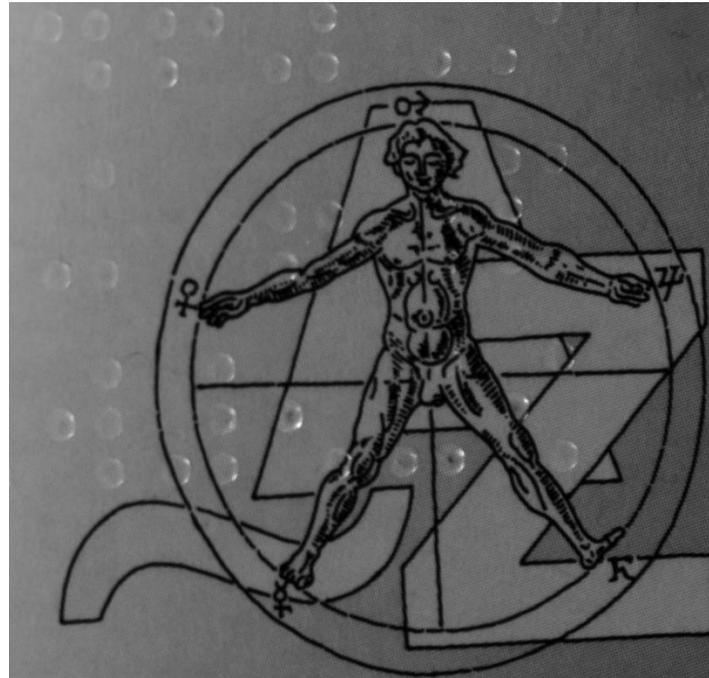
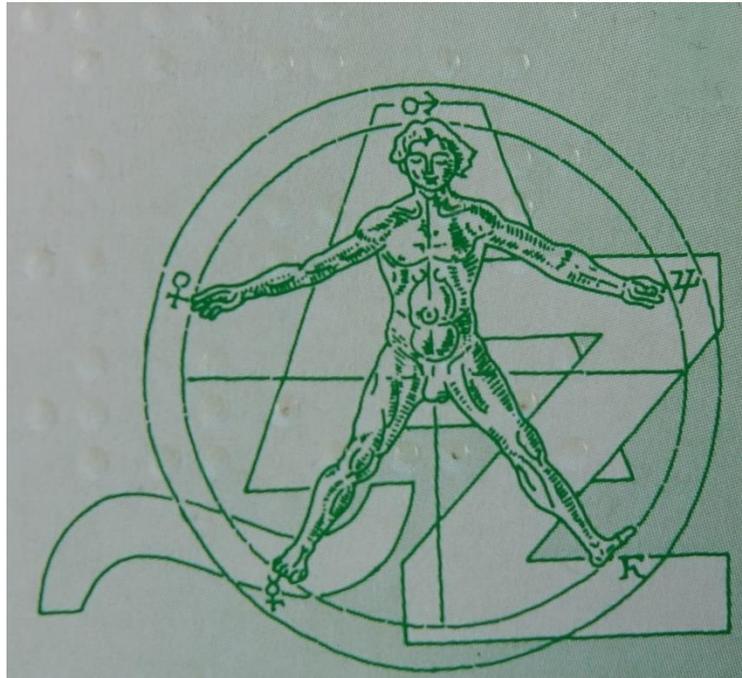


Albedo
(Texture)

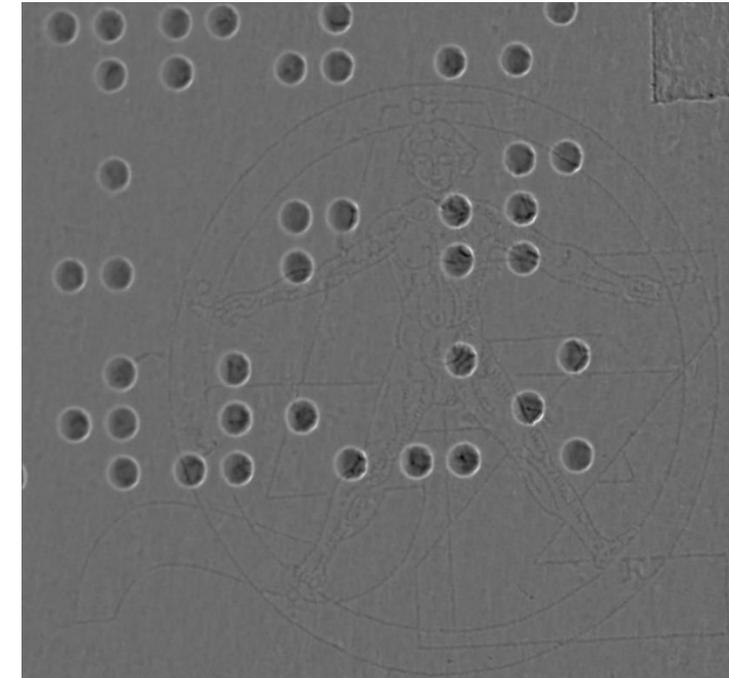
Curvature

Surface slope X

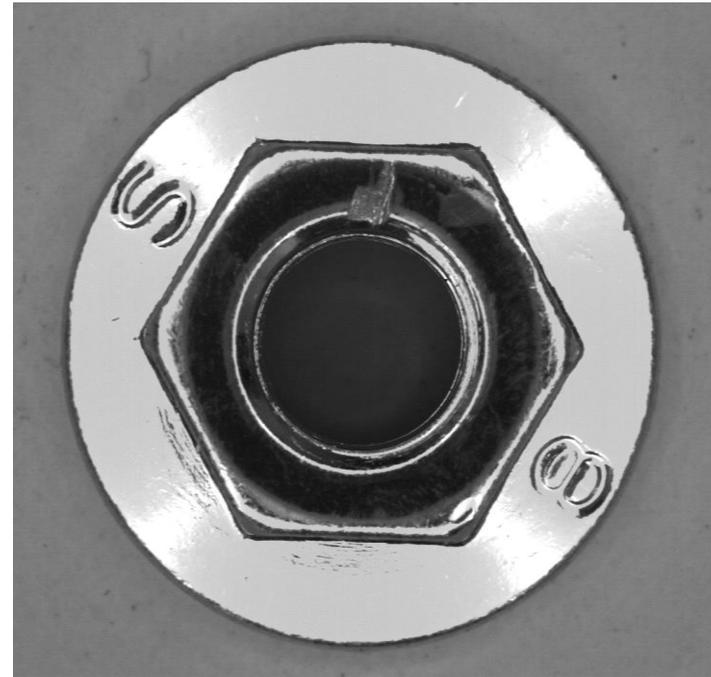
Surface slope Y



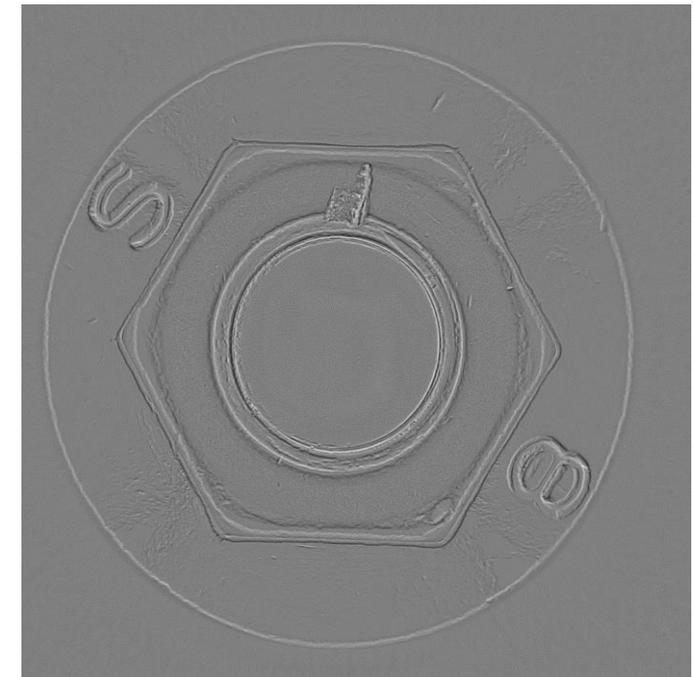
Albedo image
(Texture)



Mean curvature



Albedo image
(Texture)



Mean curvature

Introduction

Solutions

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Source:
SAC Sirius Advanced Cybernetics GmbH

SAC



Source:
KEYENCE DEUTSCHLAND GmbH

KEYENCE

Hint => Check patents



- C:/Users/Public/Documents/MVTec/HALCON-18.11-Steady/examples/hdevelop/Applications/Surface-Inspection/inspect_flooring_photometric_stereo.hdev



Varianfenster - main () - Hauptthread: 14968

Steuervariablen

WindowHandle2	H19354145360 (window)
WindowHandle	H19354145390 (window)
Message	['The defects can easily be detected', 'in the surfa...
Index	1
I	5
Slants	[39.4, 40.5, 39.5, 38.4]
Tilts	[-6.0, 83.7, 172.9, -98.2]
ResultType	['gradient', 'albedo']

```

30 * Apply photometric stereo to determine the albedo
31 * and the surface gradient.
32 Slants := [39.4,40.5,39.5,38.4]
33 Tilts := [-6.0,83.7,172.9,-98.2]
34 ResultType := ['gradient','albedo']
35 photometric_stereo (Images, HeightField, Gradient, Albedo,
36 *
37 * Display the albedo image
38 dev_display (Albedo)
39 disp_message (WindowHandle, 'Albedo image', 'window', 12, 1
40 disp_continue_message (WindowHandle, 'black', 'true')
41 stop ()
42 *
43 * Calculate the gaussian curvature of the surface
44 * using the gradient field as input for the operator
45 * derivate_vector_field.
46 * Defects are usually easy to detect in the curvature image
47 derivate_vector_field (Gradient, MeanCurvature, 1.0, 'mean_

```

Source: MVTec Software GmbH



Operator View Layout

Local shape image

Configure Flowchart

- Add step
- Cut selected step(s)
- Copy selected step(s)
- Delete selected step(s)
- Disable selected step
- Rename this step
- Comment this step

Try It

- Reset
- Run
- Run to the selected st
- Next step
- Rerun the selected ste
- Go to Quick Run Mod
- Create Quick Run Gro

Deploy

- Deploy project

Configuration

PhotometricStereo

General

Light Vector Type: Spherical

Non-Uniformity Correction: Default

Shape Smoothness: Default

Timeout: Default

Output Images

- Local Shape
- Mean Curvature
- Gaussian Curvature

Normalization: Default

Remap Factor: Automatic

Local Contrast: 2.52

Local Contrast: 2.33

Object Size: Default

Albedo: 27.82

Texture

Lighting Elements

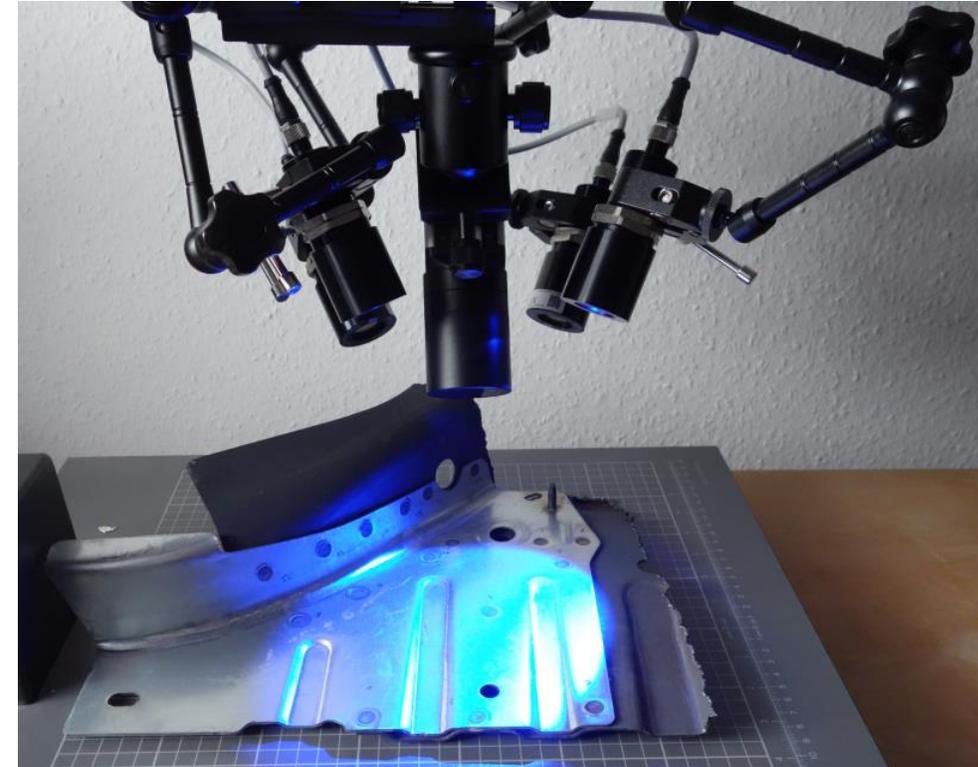
Name	Image	Zenith Angle	Azimuth Angle	Relative Intensity
LightingElement1	Flowcharts("Grab")...	45	0	1.0
LightingElement2	Flowcharts("Grab")...	45	90	1.0
LightingElement3	Flowcharts("Grab")...	45	180	1.0

Execution Messages

Design Runtime No messages

Time Description

Copyright: RAUSCHER GmbH und Matrox Imaging



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

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

COMPUTATIONAL ILLUMINATION HARDWARE

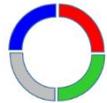


LSS-2404
Programmable
Controller

Both 4 and 12 channel versions



HPR2 Quad Ring Light

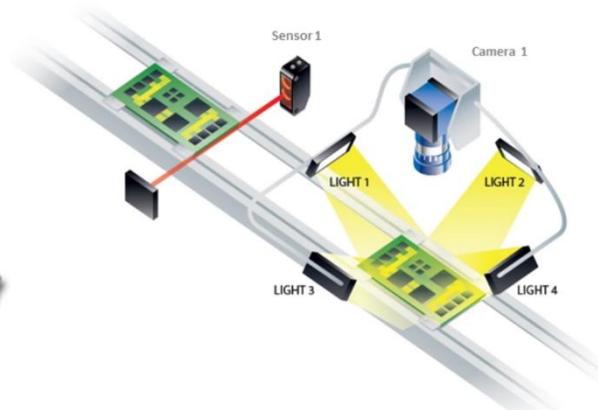


- Multi-segment lights
- Multi-spectral lights
- Multiple lights with breakout cables



Light + Camera + Bracket

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



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



Smart Vision Lights LLM

LED Light Manager

NEU

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.

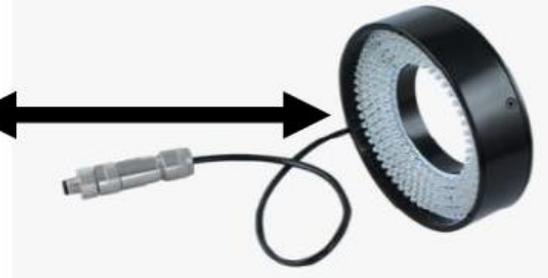
Mit dem LLM lassen sich mehrere Beleuchtungen unabhängig voneinander steuern, selbst wenn diese im **Dauerbetrieb, Multi-Drive- oder OverDrive-Modus** betrieben werden. Die Sequenzen und Intensitätsstufen werden über eine **intuitive, browserbasierte Benutzeroberfläche** programmiert.



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

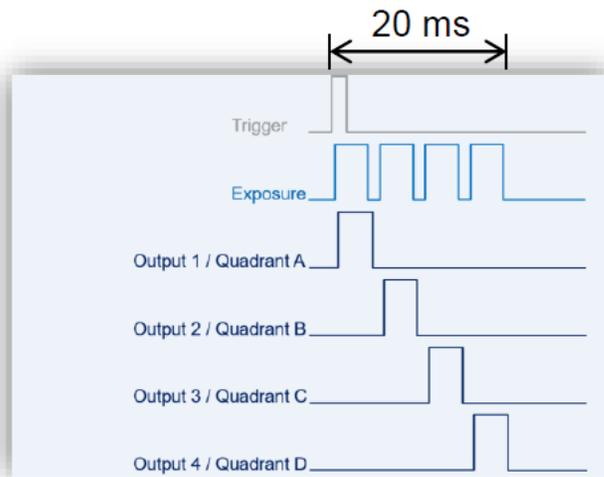
2-5 MPixel / 50-100ms => 20-100MPixel/s
(bottleneck: GigE bandwidth)
Risk of artefacts due to moving sample!

CX.I cameras (VCXG.I)



U_{EXT}: 12 ... 48 V DC
I_{OUT}: max. 2500 mA

U_{EXT} flash mode: 48 V DC
I max. flash mode: 880 mA



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: <https://www.genesi-elettronica.it/>

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

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

Introduction

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*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.

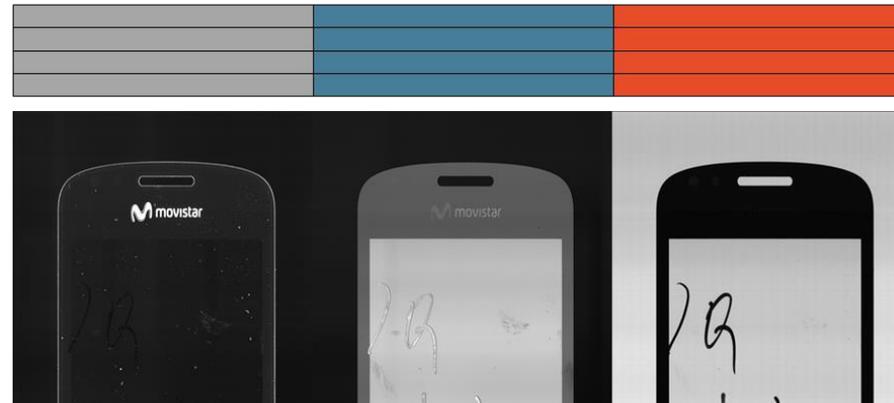
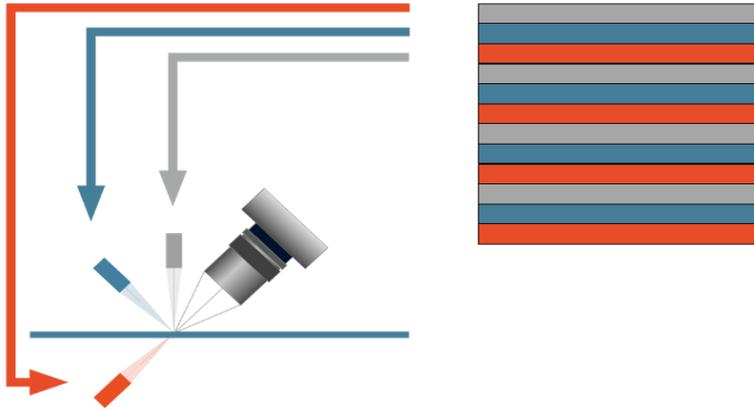
The screenshot displays the VisualApplets 3.1.0 software interface. The main workspace shows a data processing flowchart titled "Binarization by Threshold Example". The flow starts with a "TestImage" input, goes through a "Camera" module, an "ImageBuffer" (DRAM), a "Threshold" module (IS_GreaterEqual), a "Scaling" module (HierarchicalBox), and finally a "DMA0" module (DmaToPC). A "Simulation Module" is connected to the output. A callout box points to the threshold module with the text "Binarization by software programmable threshold".

On the right side, the "DRC Log" window is open, showing "Netlist Generation" details. It includes a table of resource usage:

Resource	Count	Fill Level
LookupTables	24216	~ 23%
Flip Flops	24114	~ 11%
Block RAM	40	~ 6%
Embedded ALU	5	~ 0%

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

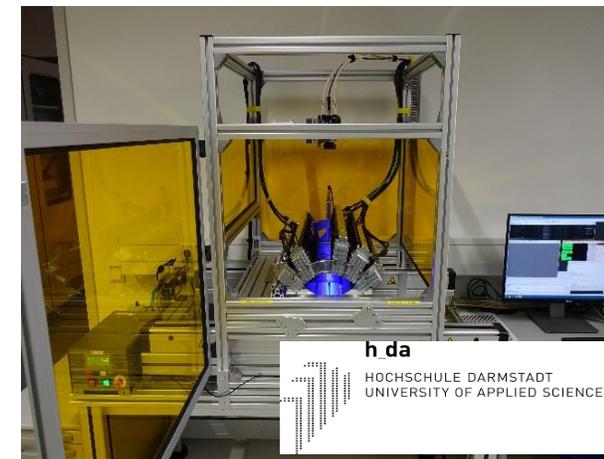
MultiChannel allows several lighting setups to be triggered on an alternating basis in combination with a synchronized camera exposure. The mixed flow of image data from the camera is rearranged within the frame grabber without CPU load.



Channel	Delay [µs]	Duration [µs]
0	2	15
2	2	15
3	2	15
4	2	15

Channel	D	Duration [µs]	Reference
0	16	CC1 [0] Start	
2	16	CC1 [2] Start	
3	16	CC1 [3] Start	
4	16	CC1 [4] Start	

Connection	Signal	Invert
CC1 Cable	CC1	<input type="checkbox"/>
Out 0	Illumination	<input type="checkbox"/>
Out 1	Illumination	<input type="checkbox"/>
Out 2	Illumination	<input type="checkbox"/>
Out 3	Illumination	<input type="checkbox"/>
Out 4	LineSync	<input type="checkbox"/>
Out 5	Low	<input type="checkbox"/>



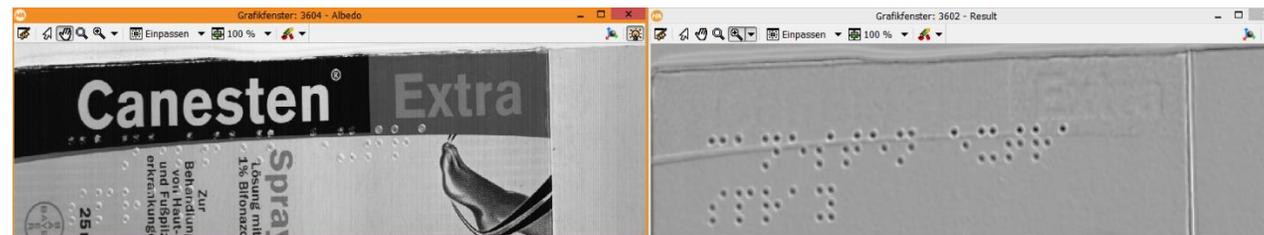
See: <http://mtd-light.de/>



```
Programmfenster - main* () - Hauptthread: 6408
*main ( : : : )
1 ChannelCount:=4
2 Tilts:=[-135,-45,135,45]
3 Slants:=[32,58,58,32]
4 open_framegrabber ('SiliconSoftware', 1, 1, 0, 0, 0, 'interlaced', 8, 'gray', -1, 'false', 'MultiChannel_RadioMetricStereo.mcf', '1', 0, -1, AcqHandle)
5 grab_image (Image, AcqHandle)
6 get_image_pointer1 (Image, Pointer, Type, Width, Height)
7 gen_empty_obj (Images)
8 for ChannelIndex := 1 to ChannelCount by 1
9   crop_rectangle1 (Image, ImageTemp, 0, Width*(ChannelIndex-1)/ChannelCount, Height, Width*(ChannelIndex)/ChannelCount)
10  concat_obj (Images, ImageTemp, Images)
11 endfor
12 photometric_stereo (Images, HeightField, Gradient, Albedo, Slants, Tilts, 'all', 'poisson', [], [])
13 derivate_vector_field (Gradient, Result, 3, 'mean_curvature')
```

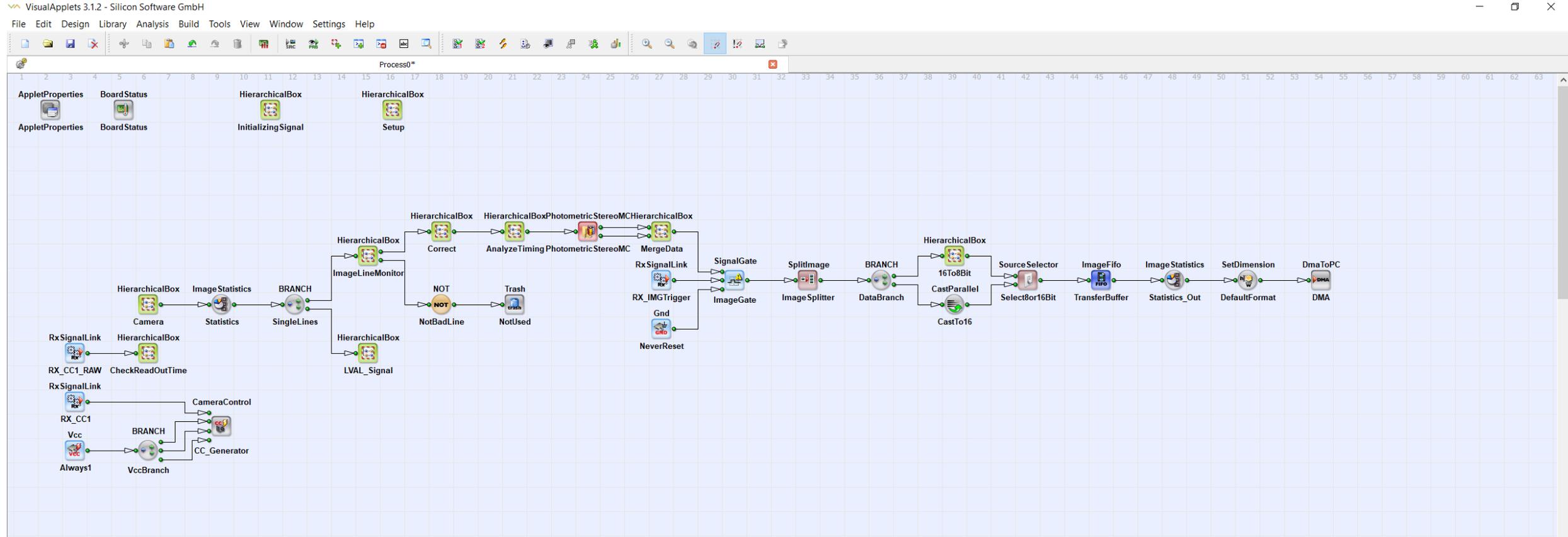
Just a few lines of HDevelop code are needed to:

- 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!)**

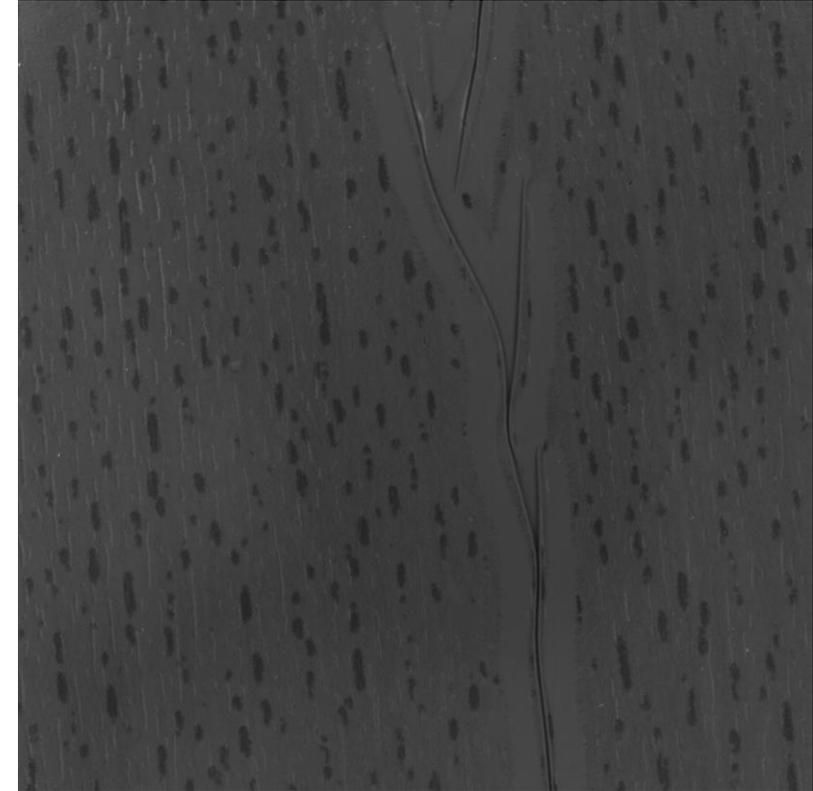
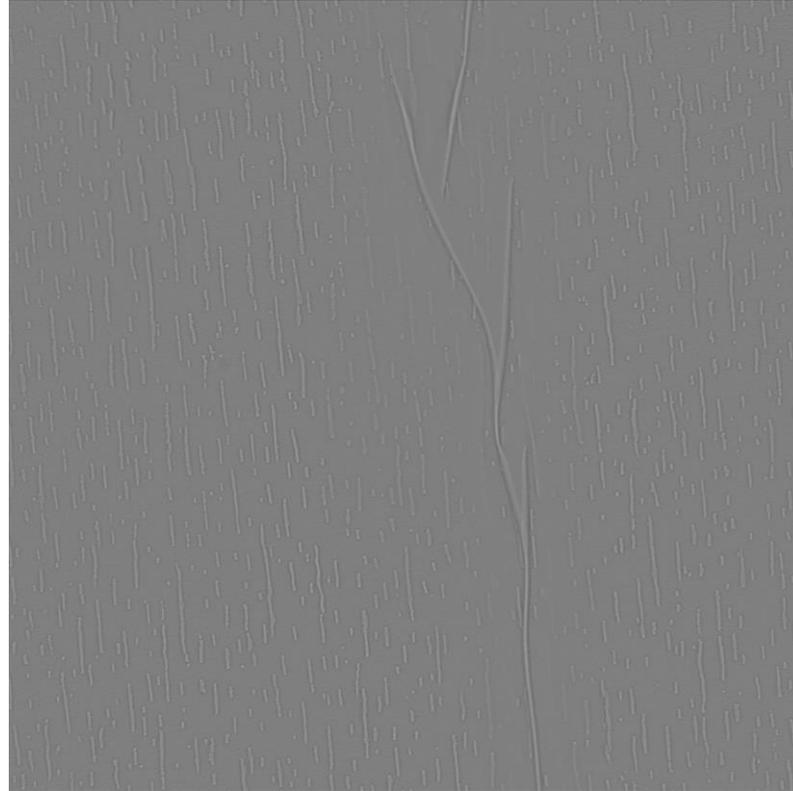
FPGA based Photometric Stereo



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 elixa+ (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

- 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)



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