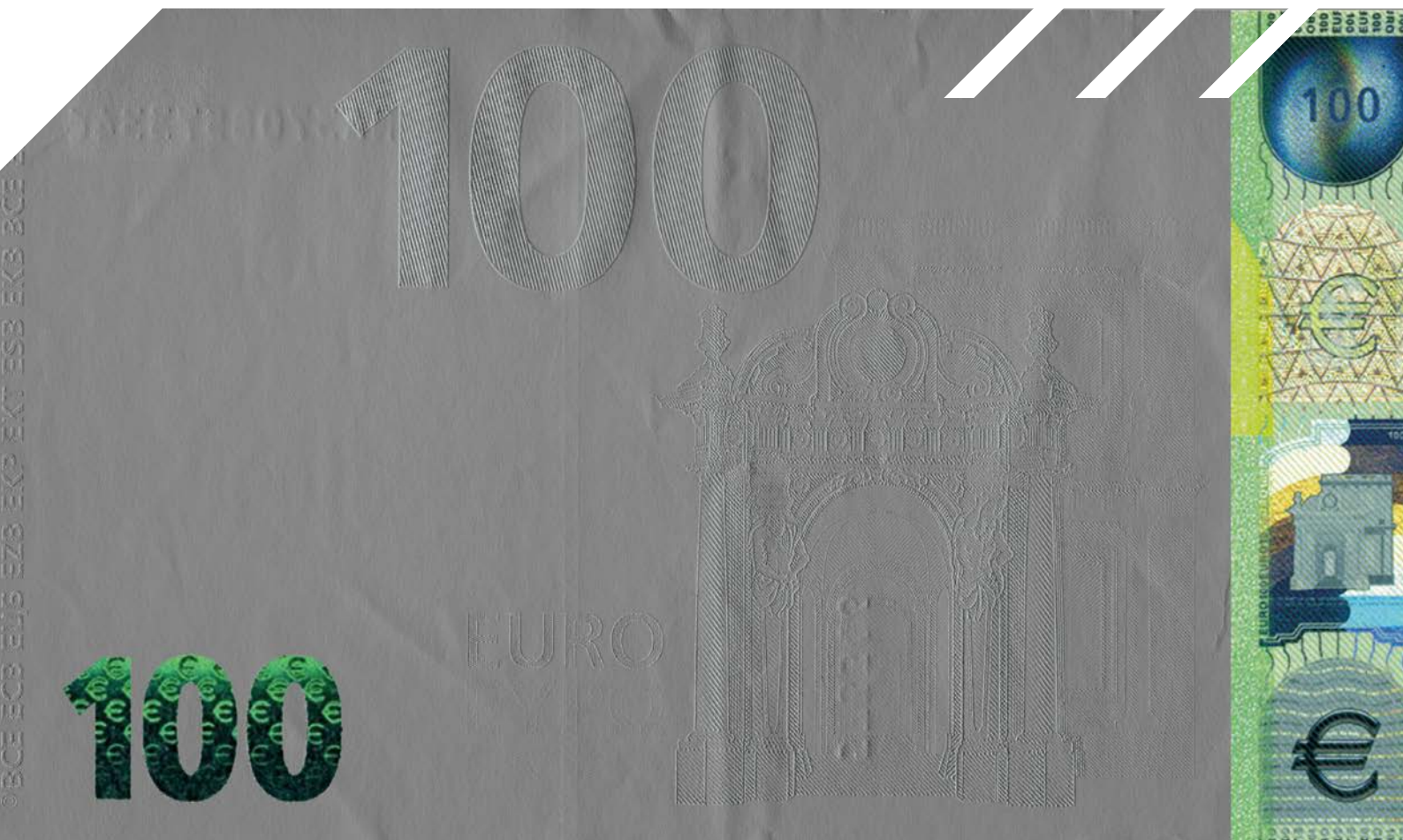


# HIGH-PERFORMANCE VISION SYSTEMS FOR CURRENCY & IDENTITY

Real-time inline quality inspection  
Authentication of novel security features



# FROM NEEDS TO RESEARCH AND INNOVATION

Our journey began 1994 when the Oesterreichische Banknoten- und Sicherheitsdruck GmbH asked us to develop an optical inline inspection system for banknotes. At that time, none of the existing systems were able to reliably check the quality of banknotes at the required speed of 10 m/s.

As a partner of the security printing industry we have developed answers to address this challenging problem: our inline quality inspection systems. Today we are the world market leader for single note inspection technology.

## WE OFFER

- deployment of leading edge solutions such as high-performance inspection systems
- development of novel technologies for the security printer market, such as high-speed sensors and embedded interfaces
- independent benchmark studies for technology comparison
- performance assessment of novel security features
- holistic approach and multidisciplinary design including optics, mechanics, electronics, image processing, heat management.

## OUR PARTNERS ENJOY

### CUSTOMISED SOLUTIONS TO FIT THE APPLICATION NEEDS

- industrial standards
- concepts based on sectoral knowledge and customer needs
- innovative technologies for demanding tasks of fast image acquisition and processing
- fast and easy deployment, configuration and customization of systems and solutions

## FIELDS OF APPLICATION

Inline and offline inspection

Actual

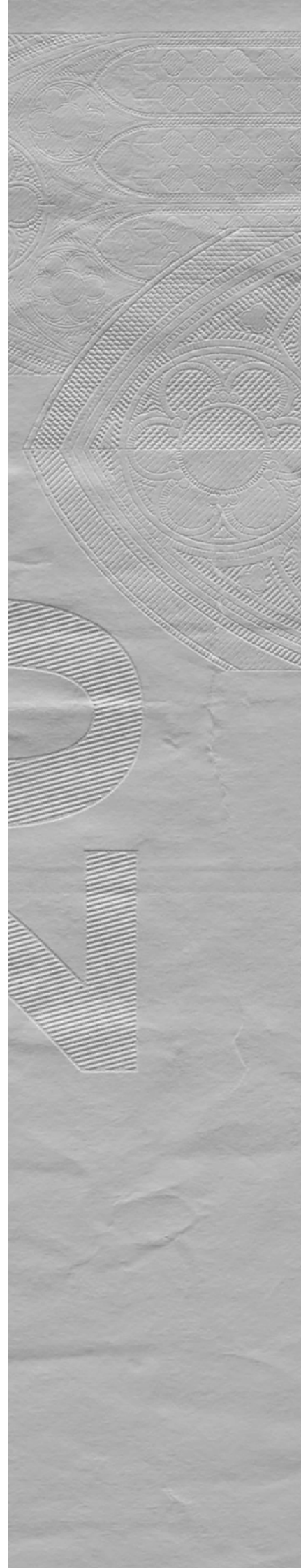
- banknotes
- identity cards (passports)
- coins
- postage stamps

Additionally

- credit cards
- cheques
- stock certificates
- tamper-evident labels
- security tapes
- product authentication

### CLIENTS

- Oesterreichische Banknoten- und Sicherheitsdruck GmbH
- European Central Bank
- United States Federal Reserve System
- Giesecke+Devrient





## OUR RESEARCH TOPICS

High-Performance 2D and 3D Image Acquisition	p. 2
High-Performance Image Processing	p. 3
Intelligent and AI-Based Algorithms	p. 4
Embedded Hardware and Real-Time Software	p. 4

## OUR SYSTEMS & SOLUTIONS

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2D Inspection of RGB and IR Features	p. 8
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## STUDIES

Independent Benchmark Studies	p. 16
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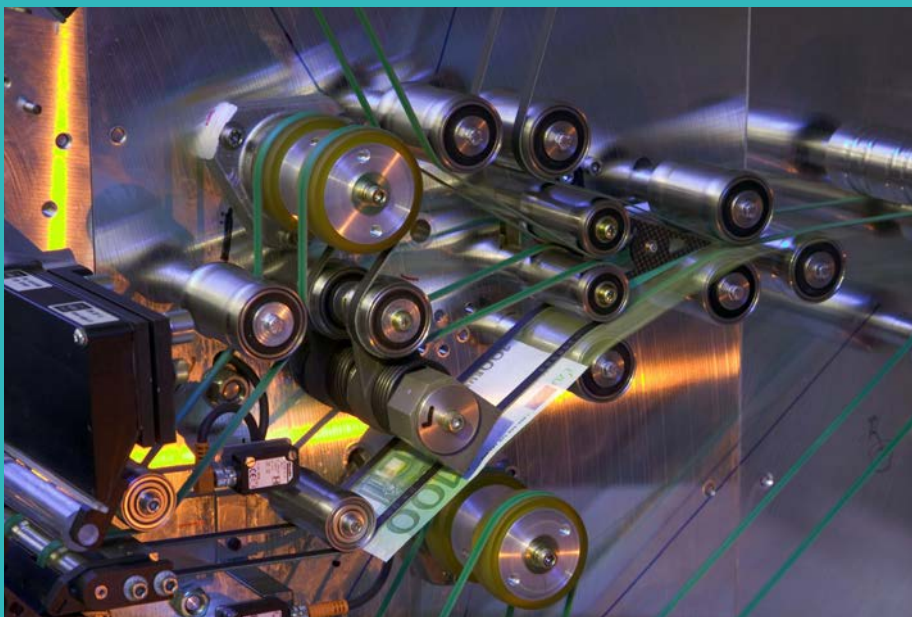
# OUR RESEARCH TOPICS

High-Performance 2D and 3D Image Acquisition

High-Performance Image Processing

Intelligent and AI-Based Algorithms

Embedded Hardware and Real-Time Software



High-performance inline acquisition inside the banknote sorting machine.

# HIGH-PERFORMANCE 2D AND 3D IMAGE ACQUISITION

The main hardware components are the embedded smart xposure:camera and the xposure:flash. Our 3D microscopy technology enables forensic inspection of security documents. In addition we can acquire security documents in a very high resolution (e.g. 0.05 mm) and multiple wavelengths such as RGB, various IR wave-lengths and UV fluorescence.

- xposure:camera: 600.000 lines/s
- xposure:flash: ultra-fast strobing at 600.000 flashes/s
- xposure:photometry: fast processing of photometric stereo calculations in camera FPGA

//01 xposure:camera



//02 xposure:flash



//01

//02

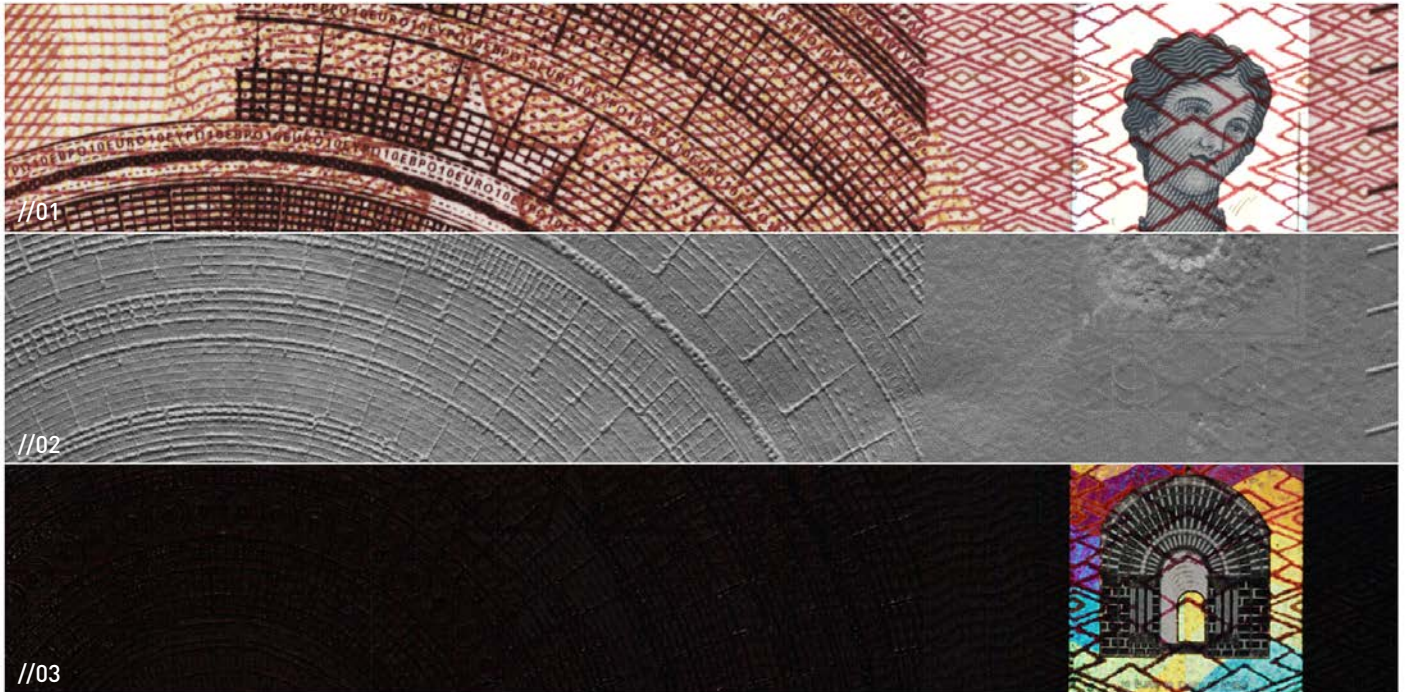


//03

//04

//03 AIT xposure technology: Yen banknote, resolution: 0.05 mm  
Inspection in real-time at 10 m/s

//04 State-of-the-art: Yen banknote, resolution: 0.20 mm



//01 10 EUR banknote color image //02 fine surface structures of intaglio print //03 OVD / hologram detection

# HIGH-PERFORMANCE IMAGE PROCESSING

WE RESEARCH AND DEVELOP FOR THE SECURITY DOCUMENT MARKET: INLINE COMPUTATIONAL IMAGING (ICI) – THE NEXT GENERATION OF INDUSTRIAL INLINE INSPECTION

With our award winning Inline Computational Imaging software approach also embossing, tactile elements and other security features can be inspected and authenticated.



## LIGHT FIELD FROM MOTION

- single sensor technology for simultaneous light field and photometric stereo capture
- compact industry-compatible inline imaging setup
- multi-line scan acquisition
- 3D light field from motion

## ALGORITHMS

- acquisition, rectification, feature extraction, stereo matching, depth refinement, texture enhancement
- 3D from multiple viewing and illumination angles
- globally correct and height details
- flexible dark, bright field imaging

## APPLICATIONS

- inspection of highly glossy surfaces
- simultaneous 2D & 3D imaging
- material classification using reflection properties (BRDF)

# INTELLIGENT AND AI-BASED ALGORITHMS

Inspection tasks in security printing industry are rather complex and have a large variety of parameters and configurations. Artificial intelligence (AI) offers data based analysis of the underlying processes and can therefore ease the configuration process, derive conclusions about the inspection and authentication process and reveals insights into the overall production process.

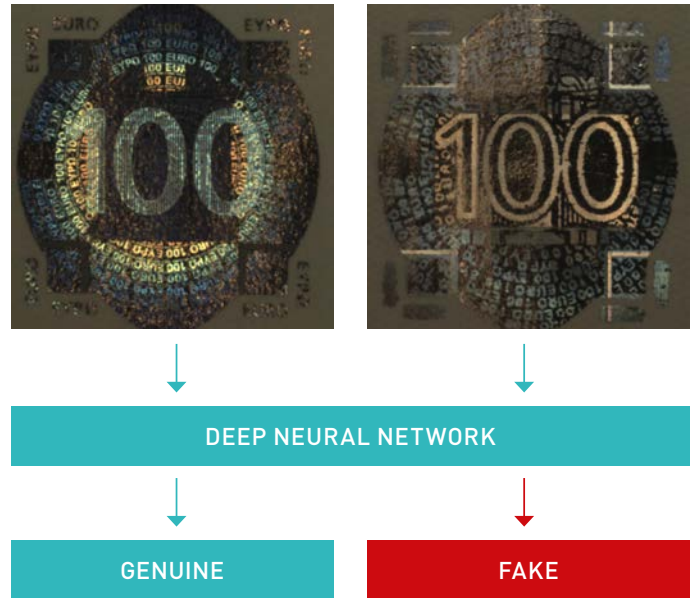
## ENABELING DEEP LEARNING FOR CURRENCY & IDENTITY APPLICATIONS

- fitting the network architecture and reducing its complexity for specific customer needs
- optimizing networks for customer requirements
- generative adversarial networks
- convolutional neural networks
- deep embedding learning

## AI-BASED INDUSTRIAL VISION

- simulation of artificial data in order to enrich training data sets
- overfitting countermeasures
- anomaly detection
- one class learning

Deep learning for detecting faked holograms



# EMBEDDED HARDWARE AND REAL-TIME SOFTWARE

Our in-depth knowledge about dedicated hardware architecture as well as high-speed data-transfer (e.g.10 GigE) enables us to further optimize our image processing systems in terms of run-time, robustness, sustainability, as well as cost factors.



Embedded Vision Box PC LeMans by AIT and Imago Technologies <https://imago-technologies.com>

# OUR SYSTEMS & SOLUTIONS

## 2D INLINE AND OFFLINE INSPECTION

- UV Fluorescence Features
- RGB and IR Features
- OVDs, Holograms and more

## 2,5D AND 3D INLINE AND OFFLINE INSPECTION

- Surface Structures
- Microscopy for Forensic Analysis
- Security Features

## CDI2 INTERFACES AND SIMULATORS



© Markus Hruska

Inline UV Fluorescence Inspection

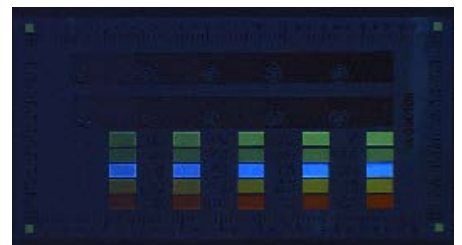
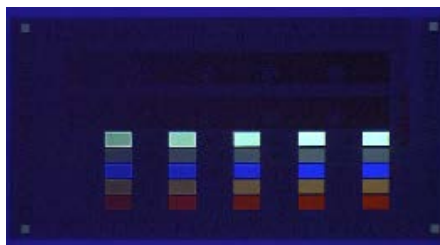
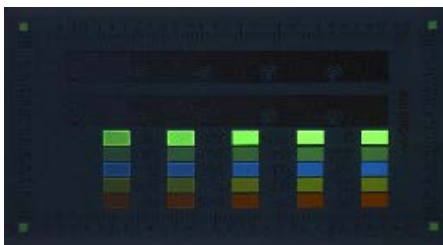
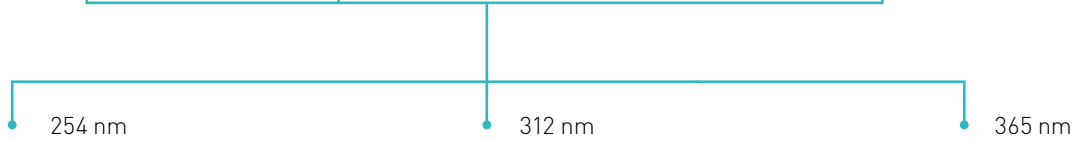


# 2D INLINE AND OFFLINE INSPECTION OF UV FLUORESCENCE FEATURES

Through the combination of special illuminations, optics and cameras, we achieve high inline inspection speeds in real-time. The entire document as well as the amount, length and colour of security threads can be examined in one pass.

speed: up to 50 banknotes /s  
resolution: 0.20 mm

The inspection makes security features visible under UV light. Their response at different wavelengths is varying.



Offline study AIT together with OeBS

# 2D INSPECTION OF RGB AND IR FEATURES

Simultaneous acquisition of human visible and machine readable infrared wavelengths with only one exposure: camera and one lens. This reduces the effort and material used and thus the costs. In addition, exposure:flash provides homogeneous illumination.

Visible (RGB) and infrared (850 nm) images of a 20 EUR banknote.



Human visible color features

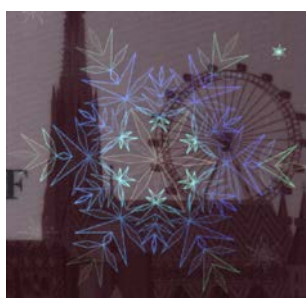


Machine readable infrared features

	<b>STATE-OF-THE-ART</b>	<b>AIT TECHNOLOGY</b>
Speed	40 banknotes / s	up to 50 banknotes / s
Resolution	0.20 mm	0.10 mm

# 2D INSPECTION OF OVDS, HOLOGRAMS AND MORE

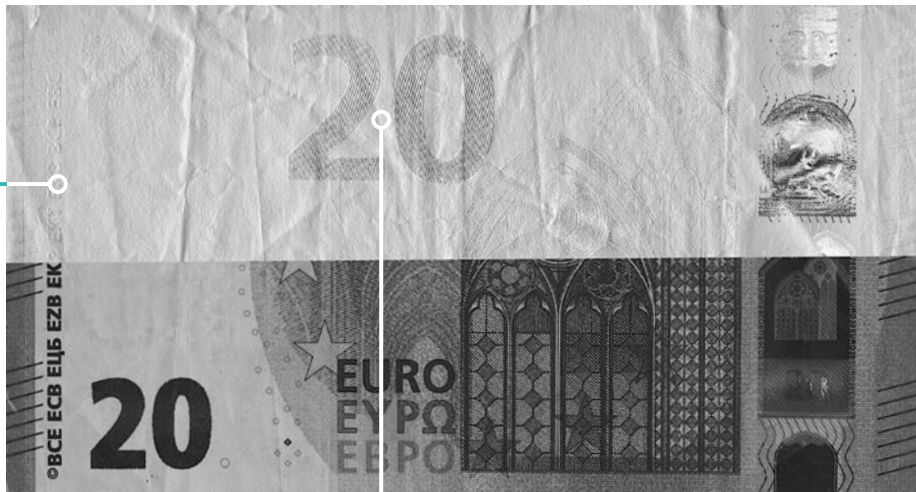
The inspection of optical security features places high demands on image processing systems. Biggest challenge to automatically inspect these features is the lack of standardized methods that mimic the human perception. Our leading edge technologies enable us to perform this task comparable to the human eye, even at the highest speeds.



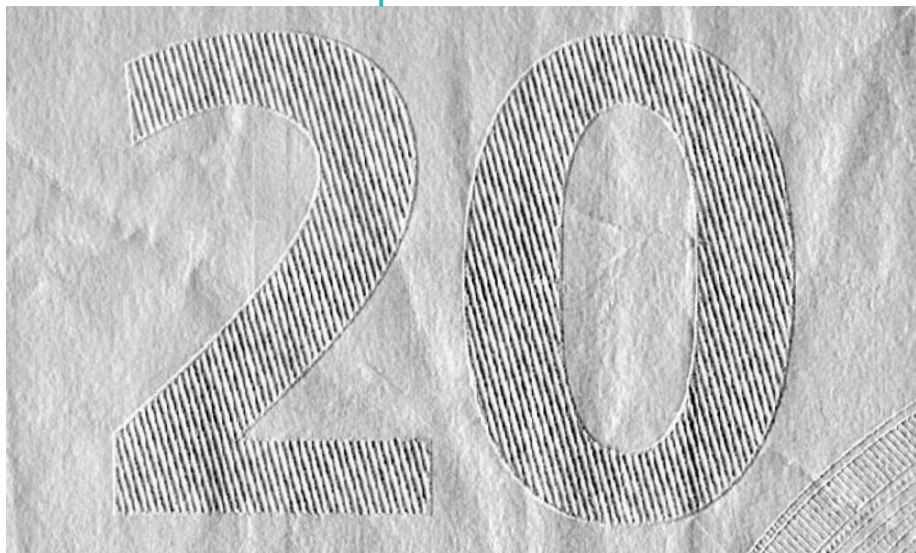
# 2,5D INLINE INSPECTION OF SURFACE STRUCTURES

The gradient image highlights tiny defects in the 3D surface structures and thus unveils e.g. tactile features, missing intaglio print, bends and wrinkles. The AIT xposure:camera with integrated photometric stereo imaging acquires the albedo and gradient image simultaneously. This unprecedented acquisition speed and resolution is possible by photometric stereo processing directly inside the FPGA of the smart camera.

- Resolution: 50  $\mu\text{m}$
- Speed: 10 m/s
- Output: 200.000 albedo and gradient lines/s images



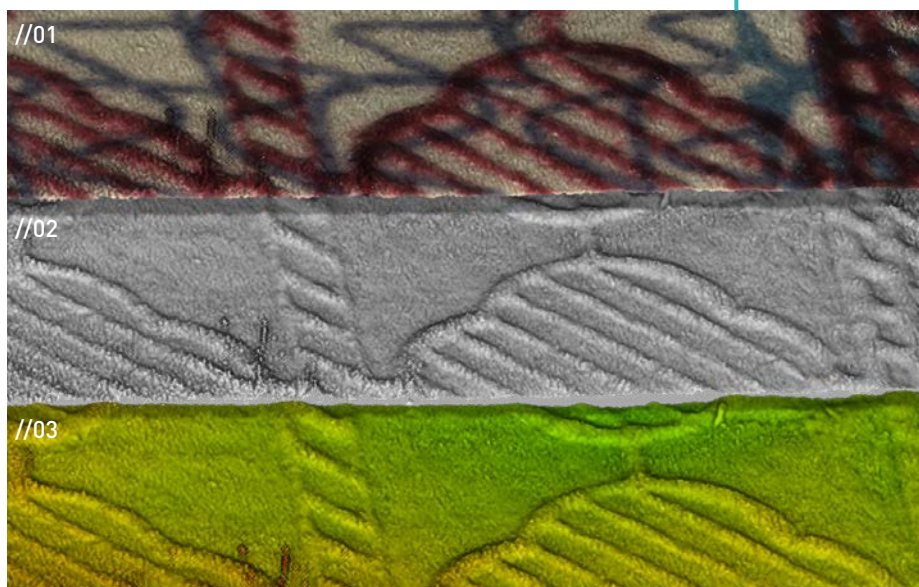
Simultaneous acquisition of albedo (lower part) and gradient image (upper part)



# 3D INLINE MICROSCOPY FOR FORENSIC ANALYSIS

In our recent research we investigate the potential of 3D microscopy for real-time inline forensic analysis of security features. Initial results show that in the near future it will be possible to inspect not only selected sections but also the entire security feature in real time.

- Sampling: 0.7  $\mu\text{m}$
- FOV: 1.6 mm
- Resolution: 3.5  $\mu\text{m}$
- Depth Resolution: 3.9  $\mu\text{m}$
- DOF: 160  $\mu\text{m}$

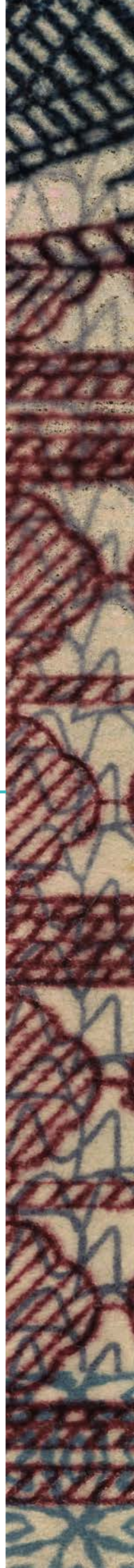


01// albedo point cloud

02// non color point cloud

03// depth

0,3mm  0mm



# 3D INSPECTION OF SECURITY FEATURES

By alternating the illumination and the camera view from multiple angles 3D security features can be detected, e.g. intaglio printing, blind embossing and laser engraving.

## TACTILE FEATURES

- Typical thickness 30-150  $\mu\text{m}$
- Different shapes and combinations with colour
- May be used to achieve optical variable effect

## LASER ENGRAVINGS ON ID-CARDS

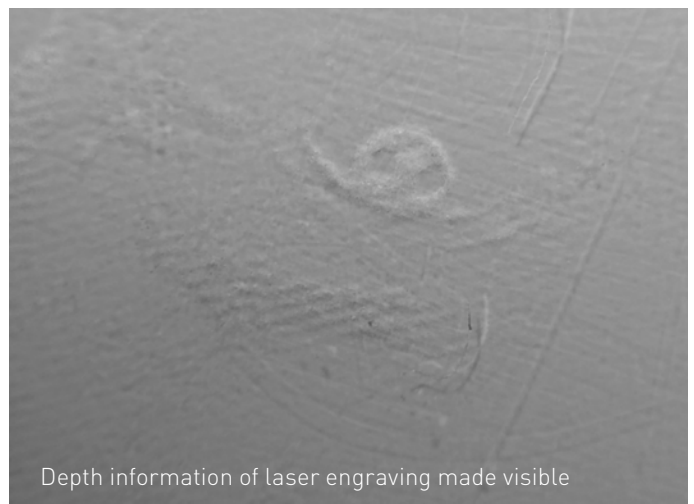
- Height-like structure of related print inside security documents can be made visible
- High resolution in combination with handheld devices



Combination of smart phone and Doculus Lumus for id-card inspection



High-resolution image with Doculus Lumus



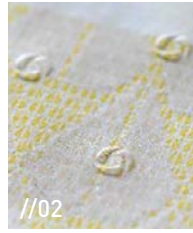
Depth information of laser engraving made visible

//01 Intaglio



//01

//02 Emboss & OVD



//02

//03-04 Gloss Coating & Holograms



//03



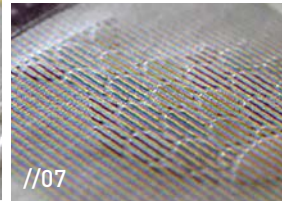
//04



//05



//06



//07

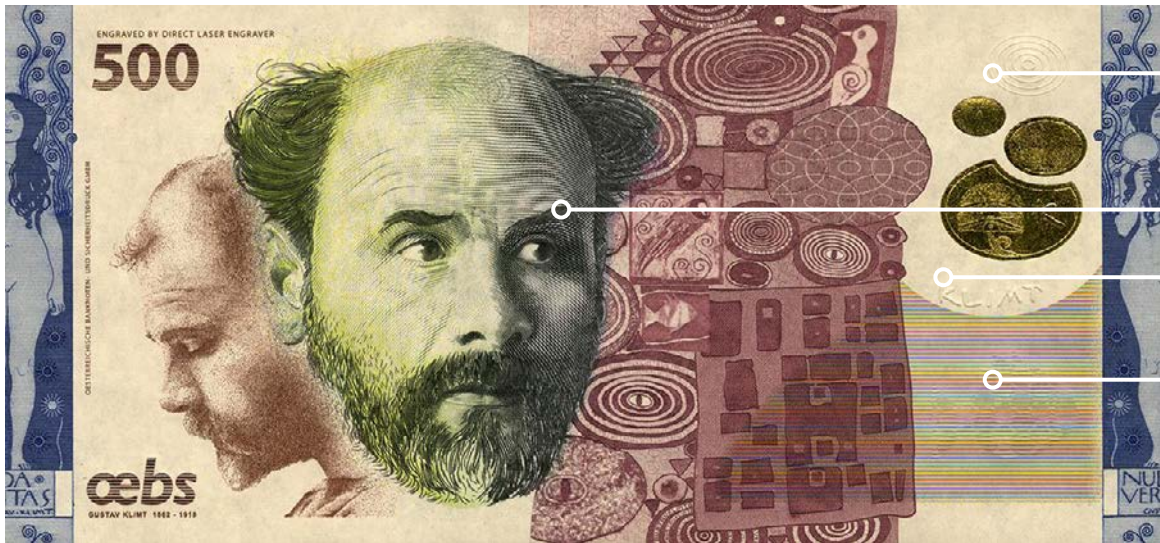


//08

//05-06 Blind Embossing

//07-08 Color Embossing

Test banknotes courtesy of OeBS.



05

01

06

07



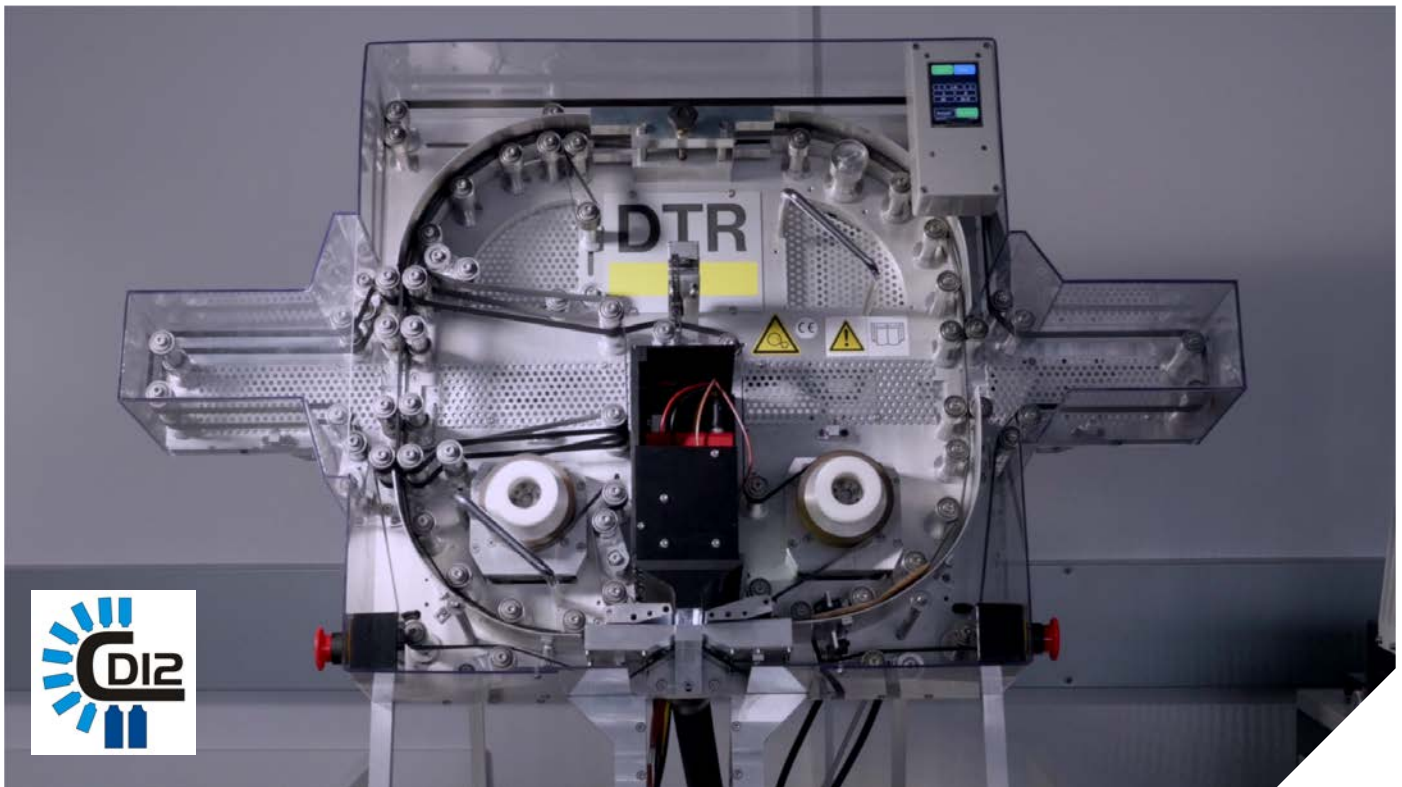
02

03

08

04

Test banknotes courtesy of OeBS



CDI2 test setup by DNB and AIT

## CDI2 INTERFACES AND SIMULATORS

In a joint project between the Eurosystem and the US Federal Reserve we developed CDI2, the Common Detector Interface Standard 2. This standard specifies all interfaces for e.g. mechanics, electronics and communication between used note sorting machines and sensors from different suppliers.

The CDI2 standard

- enables integration of a camera system into sorting machines
- enables new ways of sensors development
- defines sensor fusion capabilities to share data/results of different sensors
- provides new opportunities to enhance note processing in banknote sorting
- promotes global standardization and enhanced note analysis.

### CDI2 STANDARDIZATION WORKGROUP

Eurosystem, Federal Reserve, Oesterreichische Banknoten- und Sicherheitsdruck GmbH, AIT, Banque de France, De Nederlandsche Bank, Lawrence Livermore National Laboratory

**CENTRAL  
BANKING**  
AWARDS

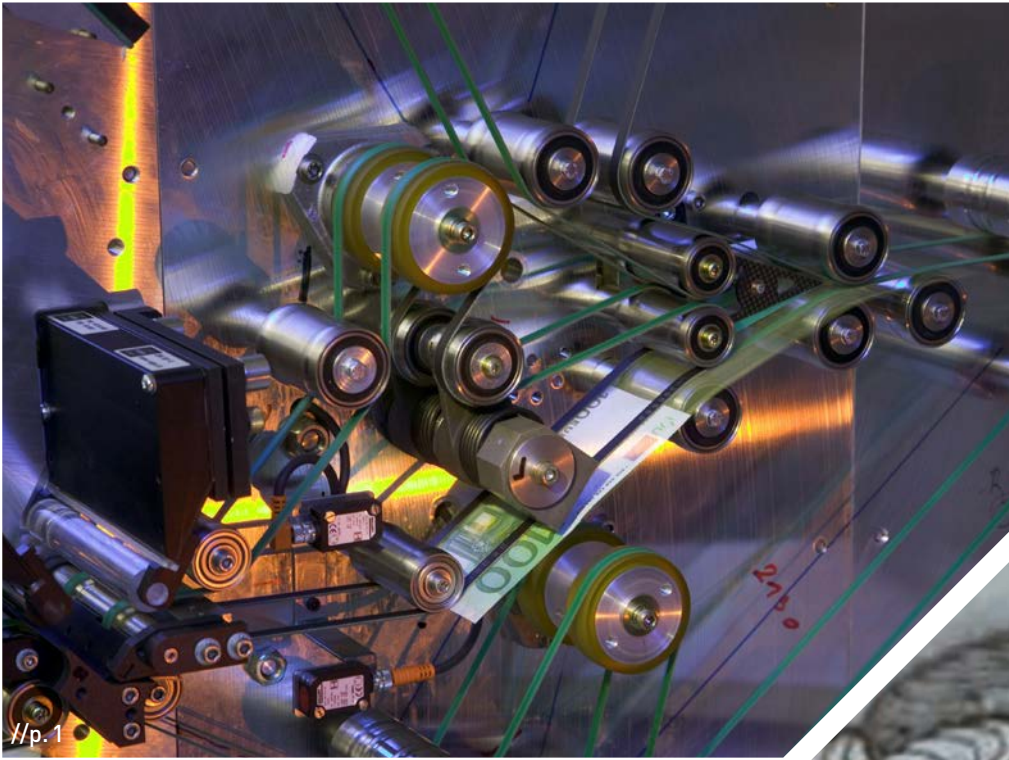
Central Banking Award 2021



Winner of the 2019 IACA  
Excellence in Currency Awards,  
Best Banknote Processing Innovation

CDI2 Specification  
[www.ecb.europa.eu/euro/cashprof/  
cdispec/html/index.en.html](http://www.ecb.europa.eu/euro/cashprof/cdispec/html/index.en.html)

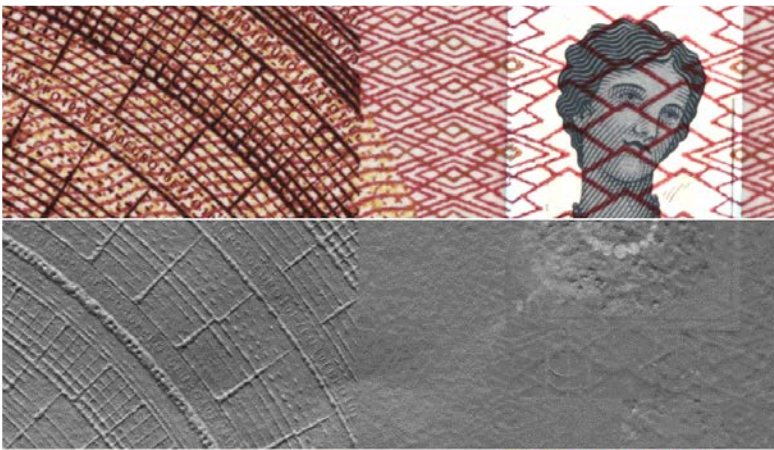




//p. 1



//p. 8 & 16



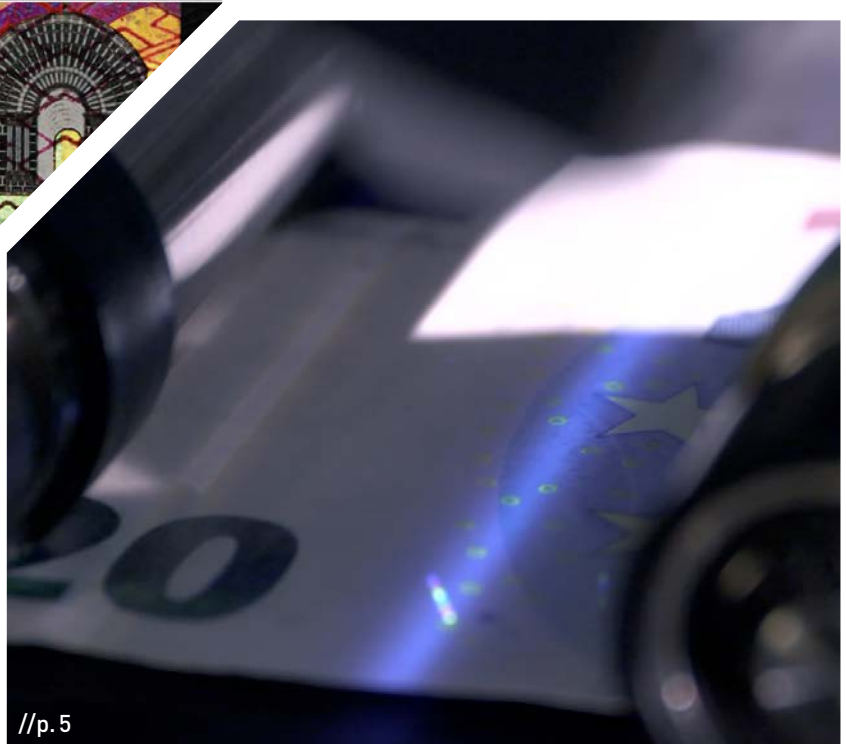
//p. 12



//p. 3



//p. 8



//p. 5

# STUDIES

Independent Benchmark Studies

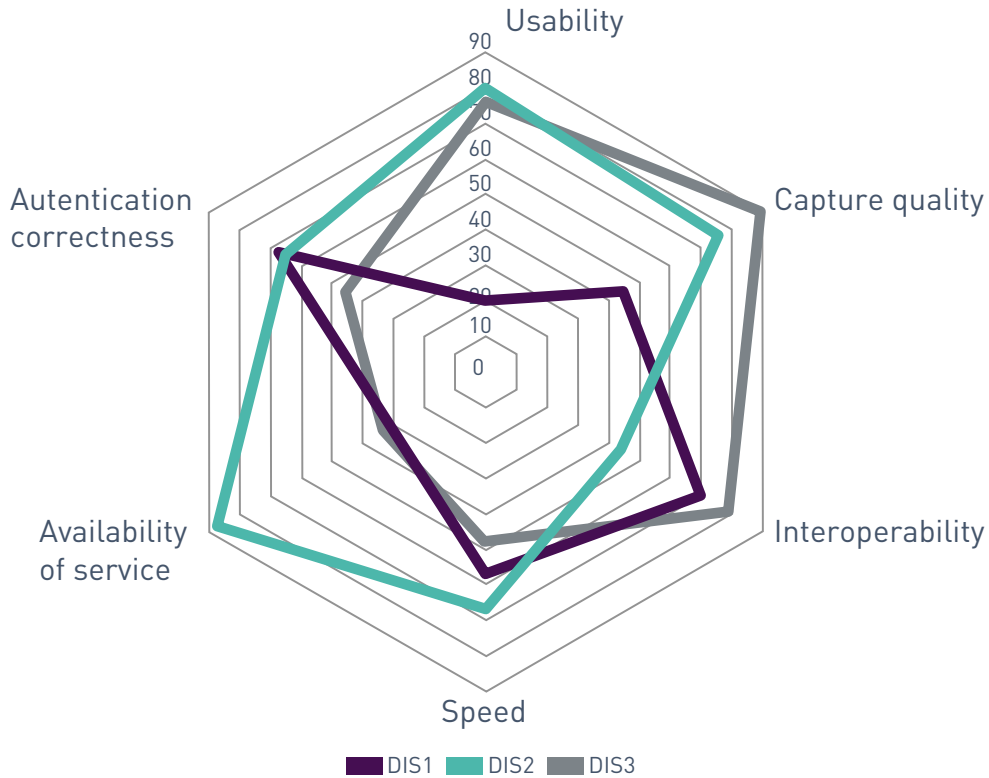
Performance Assessments



Sample ID-card

# INDEPENDENT BENCHMARK STUDIES

Document reading devices offer a large variety of detection features. We perform independent benchmark studies to compare document inspection systems (DIS) for operational use. This enables end users to rely on independent results and vendors to improve device features and to validate the results.



## PERFORMANCE ASSESSMENTS OF SECURITY FEATURES



To evaluate the performance of novel security features, we develop systems and software for qualitative and quantitative assessment. Also concepts for inspection of novel security features are investigated.

THE AIT AUSTRIAN INSTITUTE OF TECHNOLOGY –  
AUSTRIA'S LARGEST RESEARCH AND TECHNOLOGY ORGANISATION

**1,400** RESEARCHERS  
**9** LOCATIONS  
**7** CENTERS



## HIGH-PERFORMANCE VISION SYSTEMS

Our research group High-Performance Vision Systems at the AIT Austrian Institute of Technology is a multidisciplinary team and compiles a broad spectrum of competences. We foster a holistic approach to enable high-performance vision.

As part of the AIT Center for Vision, Automation & Control we develop technologies and solutions for high performance industrial image processing, covering all aspects of automated optical inspections.

### WE FOCUS ON

- high-speed sensing and embedded computing
- computational imaging for simultaneous 2D & 3D imaging
- deep learning / AI for industrial inspection

## TOGETHER WITH YOU

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### MARKUS CLABIAN

Tel +43 (0) 664 8157890  
Giefinggasse 4, 1210 Wien  
markus.clabian@ait.ac.at  
ait.ac.at/hvs

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### JÖRG BRODERSEN

Tel +43 (0) 664 8251122  
Giefinggasse 4, 1210 Wien  
joerg.brodersen@ait.ac.at  
ait.ac.at/hvs