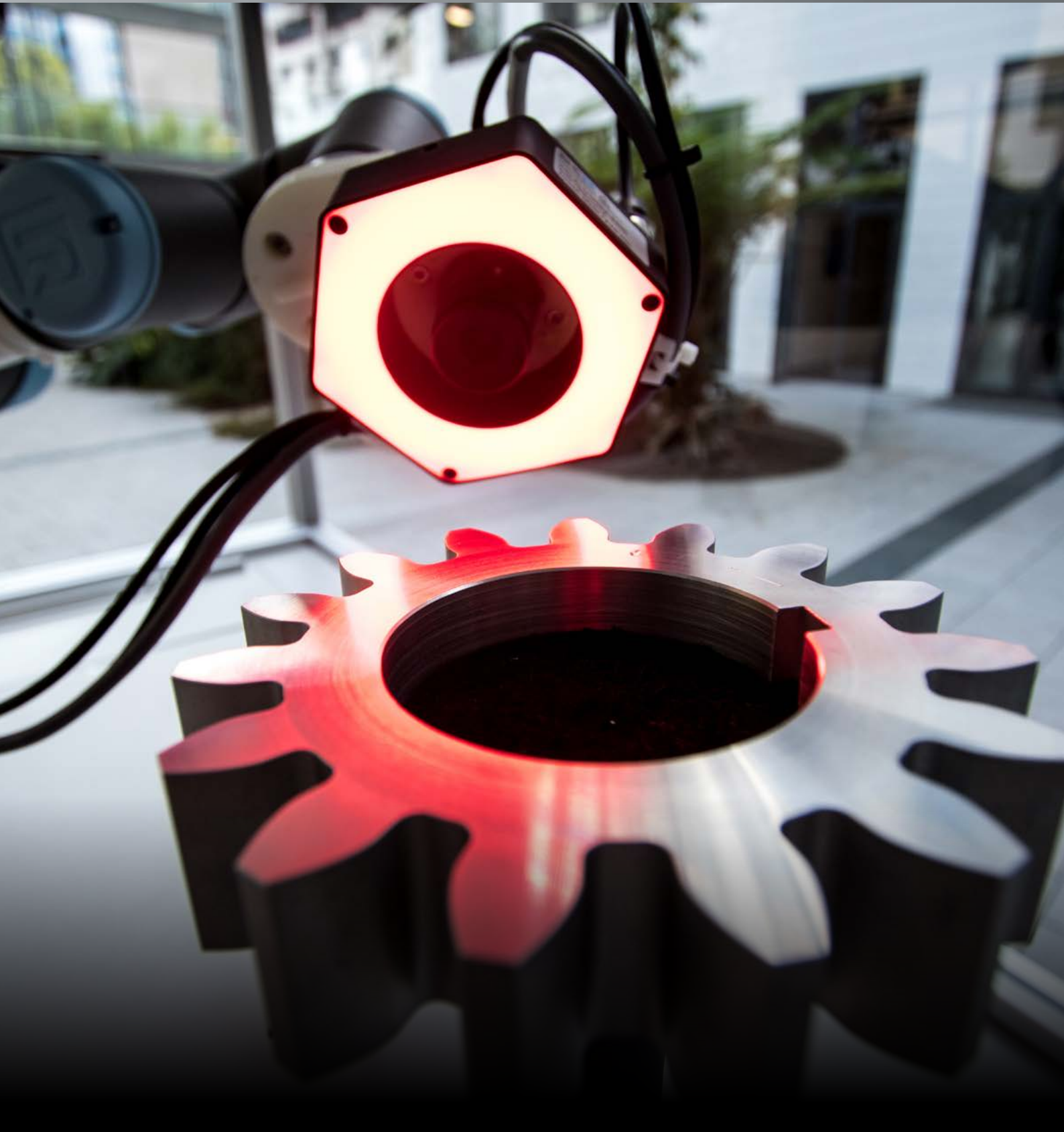




IMAGE PROCESSING



MARKUS RAUHUT
HEAD OF DEPARTMENT



CUSTOM-MADE IMAGE ANALYSIS SOLUTIONS FOR THE PRODUCTION AND ANALYSIS OF MICROSTRUCTURES

We develop mathematical models and image analysis algorithms and convert them into efficient industrial software. We solve inspection tasks, mainly for production facilities.

The areas of application include in particular complex surface inspections and the analysis of microstructures. Our large portfolio of algorithms enables us to solve image processing tasks for which commercially available systems cannot yet be used or only partially. For these problems, we develop custom-made, sophisticated image processing solutions.

Machine learning has been an integral part of many projects and research activities in the department for years. In the area of surface inspection, hybrids of “classical” image processing algorithms and learning approaches are used increasingly. Learning methods require a large amount of annotated data, which can usually neither be financed nor generated in an industrial project. Therefore, we use model-based machine learning: We model properties of the objects to be found and use this modelling as partial input for automated processes.

Furthermore, we offer technical consulting services, for example for optimal hardware configurations in image processing systems or for the integration of additional components into an existing system. However, we also provide independent consulting in the field of optical quality control or algorithm development.

Contact

markus.rauhut@itwm.fraunhofer.de

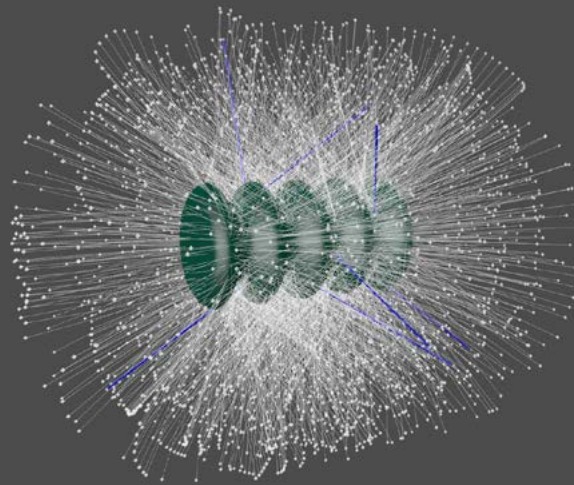
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MAIN TOPICS

- Surface and material characterization
 - Quality assurance and optimization
 - Industrial image learning
 - Virtual image processing
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1 CAD model of a test object with camera viewpoint candidates (white) and the final viewpoints selected in the optimization step (blue).

VIRTUAL IMAGE PROCESSING

Factories are getting more and more automated. Production plants are becoming more flexible, so that no new facilities have to be built when switching to new products. However, the integration of automated quality control systems is often neglected. Inspection systems, on the other hand, are inflexible and designed to inspect specific products at great expense. Virtual image processing is one way to solve this problems.

An inspection system consists of many hardware components, typically selected and parameterized by experienced engineers on the basis of physical tests. New systems are developed iteratively. Experts design an initial system, which is then modified until it can inspect the product with sufficient accuracy. These tests of different hardware solutions cost a lot of time and effort – several hours per test run. Therefore, a configuration is often chosen that works but is not optimal. The resulting sub-optimal image quality must be algorithmically compensated later.

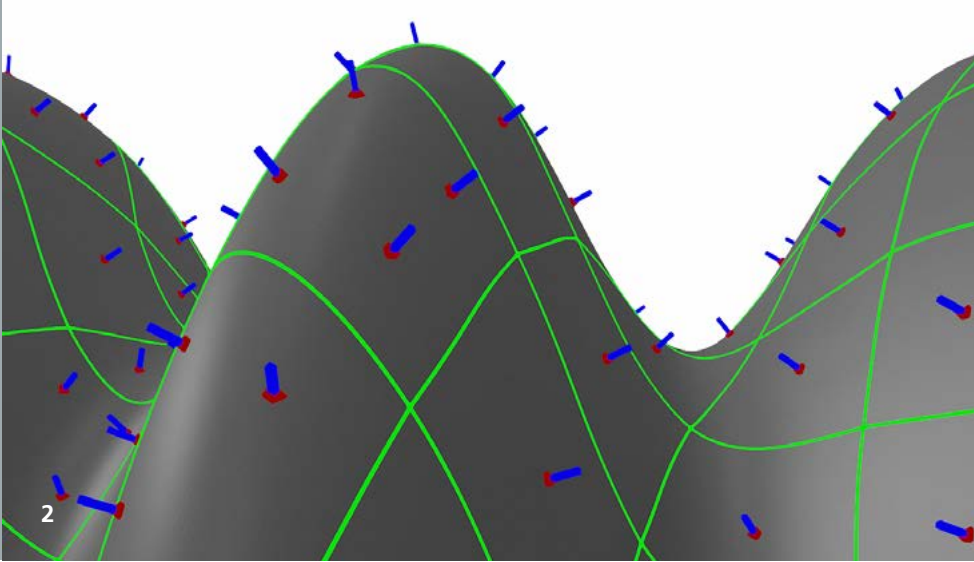
Digital twins simplify quality control

To make this process more flexible and efficient, we are developing an adaptive, simulation-based framework that will revolutionize the development process for inspection systems. In the future, industrial inspection systems will be completely virtual designed and tested for reliability using this framework.

For most of the produced components, there will be a CAD model, the so-called digital twin. Every step of the production process will be computer controlled. It will be possible to manufacture different products in small quantities with the same equipment. At the same time, the demands on quality are also growing. So what does an inspection system in such a factory have to look like? Above all, it must be possible to adapt it quickly and easily to changed production conditions. This will involve the use of several robots that can take analyzable images from free-form surfaces and even complicated geometries. The inspection system of the future will also predict how reliable it can detect certain defects at different areas of the product.

Virtualization core for planning and simulation

On the way to a complete framework for virtual inspection planning and image processing, we first optimize the positioning of product and camera; in addition, we develop simulation algorithms to generate a sufficient number of images of all defects to be found. These are often lacking in areas where defects can have devastating effects, such as turbine disks or brakes.



The virtualization core of the system consists of the components “Planning” and “Simulation”. We simulate what the camera sees and use this information to design the inspection system. The planning component calculates multiple system configurations, consisting of cameras, optics, lighting, etc., which the robot can later use for optimal inspection. The virtualization core calculates possible hardware solutions from the CAD model - the geometry - of the product and various inspection parameters such as defect types, product material and inspection speed. In addition, the user receives a series of simulated images that can be used to test the inspection system during development.

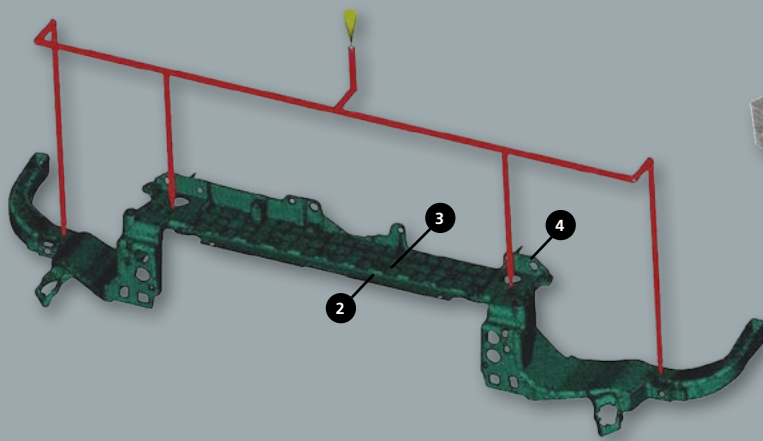
The planning component calculates an inspection process with optimal surface coverage of the product according to the previously defined requirements. With the help of the simulation component, it is possible to carry out this planning even for geometrically complex products where the automation of today’s systems has so far failed. The necessary illumination and a list of camera viewpoints are calculated from the CAD model of the product. For this process, the entire inspection environment is modelled and the behavior of the sensors is simulated using a physical based rendering. The traversal path of the camera is then planned based on a list of viewpoints.

Current research results: Position planning

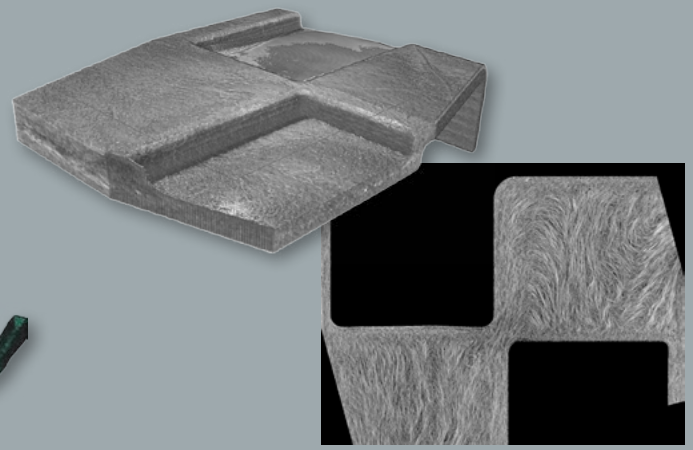
Currently we research and develop our framework on many topics in parallel: parametric surface reconstruction, active model-based position planning, camera lens modeling, position-based error augmentation and surface illumination modeling. The focus is primarily on position planning - the backbone of the overall system. We will modularly extend and supplement it with new functionality in order to be adapt the framework to product-specific requirements.

2 Close-up of the pivot points for the camera view-point candidates. A few points cover flat areas, while more points are generated in strongly curved regions





1



2

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NON-DESTRUCTIVE MICRO-STRUCTURE ANALYSIS FOR FIBER REINFORCED POLYMER PARTS

1 Long glass fiber reinforced carrier, surface mesh from Moldflow

2 – 4 Volume rendering and virtual slices of regions marked in 1, imaged by Region-of-Interest micro-computed tomography.

Coloured: diagonal component of orientation tensor in flow direction

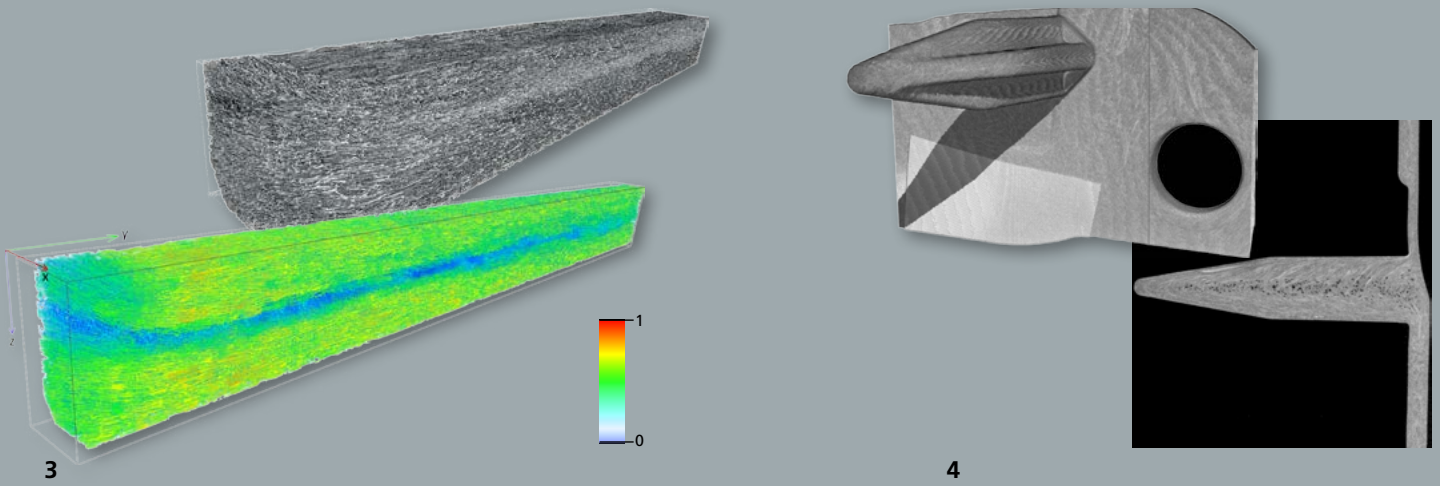
More and more often, parts made of fiber reinforced polymer replace parts formerly made of metal alloys, as they save energy due to their lighter weight while preserving the same mechanical properties. They consist of a polymer matrix and included fibers, usually made of glass or carbon. These fibers are mechanically stiffer than the polymer matrix surrounding them. This results in high mechanical strength of the composite in fiber direction. Thanks to their light weight, and their high stiffness and strength, fiber reinforced polymers are particularly well suited for light weight design for example in automobile and aircraft industry.

On the other hand, it is more difficult to design fiber reinforced polymer parts load optimized since mechanical properties like load capacity and durability depend critically on the specific micro-structure. Compared to classical materials, the relation between mechanical and micro-structural properties is less well understood – not the least since the micro-structure is more complex, just but not only due to having several components. Moreover, significant micro-structural characteristics can vary strongly within a part due to the production methods. Hence, heavily loaded and vital parts have to be reliably non-destructively tested.

Fiber orientation influences material properties

The local properties in a part vary with the spatial arrangement of the fibers due to the differing mechanical properties of matrix and fibers: Parallel fibers yield high tensile strength of the composite in fiber direction while completely randomly (isotropically) oriented fiber systems yield composites whose mechanical strength does not depend on direction. Consequently, local fiber volume fraction and local orientation of the reinforcing fibers are decisive for the behavior of fiber reinforced polymer parts.

Spatial imaging using micro-computed tomography has delivered this valuable micro-structure information already. From projections, the tomographic reconstruction generates 3D images, whose gray values essentially reflect the local X-ray absorption. Hence, glass fibers appear considerably brighter than the polymer matrix. It is impossible to identify individual fibers as image objects in 3D. However, the fiber system can be separated from the matrix easily. Based on this, the local fiber volume fraction is derived as the proportion of the numbers of fiber voxels and all voxels in the investigated region.



Algorithms calculate preferred directions based on gray values

During the last 10 years, not the least at ITWM, image processing algorithms have been developed that compute the local fiber orientation in each voxel in the fiber component based on the local gray values. The 2nd order orientation tensor is derived from these local orientations. For this analysis, the fiber diameter of 10-20 μm has to be resolved by at least three voxels. That is, for fibers that are 10 μm thick, the voxel edge length has to be below 3.5 μm . Therefore, till now, small samples of an edge length of a few millimeters had to be cut to image them that highly resolved by a cone beam. This renders the method too complicated and expensive to be used in serial testing. Even more severe, the method is not non-destructive for large parts and can thus not be used for quality surveillance.

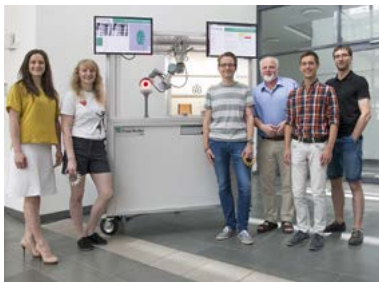
Given a dedicated setup of the tomography device, micro-computed tomography is able to image very small regions of a sample without actually cutting. This has been known for a long time. However, practically, imaging artifacts reduced the quality to an extent that prohibited the quantitative analysis of the 3D images of such »regions-of-interest«.

»3d Volant« avoids imaging artifacts and characterizes micro-structures correctly

This problem has been solved in the MEF project »3d Volant« of ITWM and the project group »NanoCT systems« of IIS. For the first time, practically relevant parts from the automotive industry have been spatially imaged by micro-computed tomography well enough for the resulting volume images of particularly interesting regions to be subsequently analyzed quantitatively. The local micro-structure of the parts can be completely described that way. Moreover, based on the 3D images, the real micro-structure can be compared to the one derived from simulating the flow in the whole part.

At the same time, new challenges arise from the opportunity to image a part of about 0.5 m length in regions-of-interest with voxel size 3 μm . The huge amounts of data generated cannot be processed interactively anymore. It is therefore planned to automatize all steps from choice of regions to be imaged to output of analysis results in an additional project.





RESEARCH GROUP BREAKS NEW GROUND IN IMAGE PROCESSING

Online inspection systems have proven themselves in many production environments. However, what happens when products become more complicated? How can an inspection system be automated despite the increasing individualization of industrially manufactured products? Answers are provided by virtual image processing, which completely simulates and optimizes the inspection process.

The cooperation between the “Computer Graphics” working group at Technical University in Kaiserslautern and the “Image Processing” department at the “High Performance Center Simulation and Software Based Innovation” in the past two years has provided important impetus. It became clear that research in the field of virtual image processing could only progress if the knowledge of different disciplines comes together. The cooperation has existed for many years and has now led to the foundation of an international research group. One step on the way to virtual inspection has already been taken: The Revolving Product Inspection EPI developed at the Fraunhofer ITWM takes into account not only general conditions such as component geometry and surface texture, but also calculates where problems may arise in the analysis.

IMAGE PROCESSING DEPARTMENT NOW A MEMBER OF EMVA



During the Control trade fair, the department “Image Processing” became a member of the European Machine Vision Association. The EMVA is a non-profit and non-commercial association representing the machine vision industry in Europe. The association was founded in Barcelona in 2003 by industry representatives from all over Europe as a network to promote the development and use of machine vision technology.

ORGANIZATION OF THE WORKSHOP “3D FIB-SEM IMAGING AND ANALYSIS”

In the project “Reconstruction of Porous Structures from FIB-SEM Images” (REPOS) of the Federal Ministry of Education and Research (BMBF), the department co-organized the workshop on 3D FIB-SEM Imaging and Analysis in October 2018. The workshop took place at KIT Campus North and focused on the acquisition of 3D Slice&View stacks and the alignment and segmentation of FIB data sets with a focus on porous materials.



Front, left to right: Yuli Afrianti, Annika Schwarz, DamjanHatić, Tessa Kuschnerus, Dr. Ronald Rösch, Petra Gospodnetić, Bess, Dr. Xiaoyin Cheng, Dascha Dobrovolskij, Markus Rauhut, Kai Taeubner, Dr. Katja Schladitz, Dr. Ali Mogiseh, Michael Godehardt, Falco Hirschenberger, Dr. Markus Kronenberger, Franz Schreiber, Konstantin Hauch, Thomas Redenbach, Dennis Mosbach, Martin Braun, Nikita Nobel, Dr. Thomas Weibel