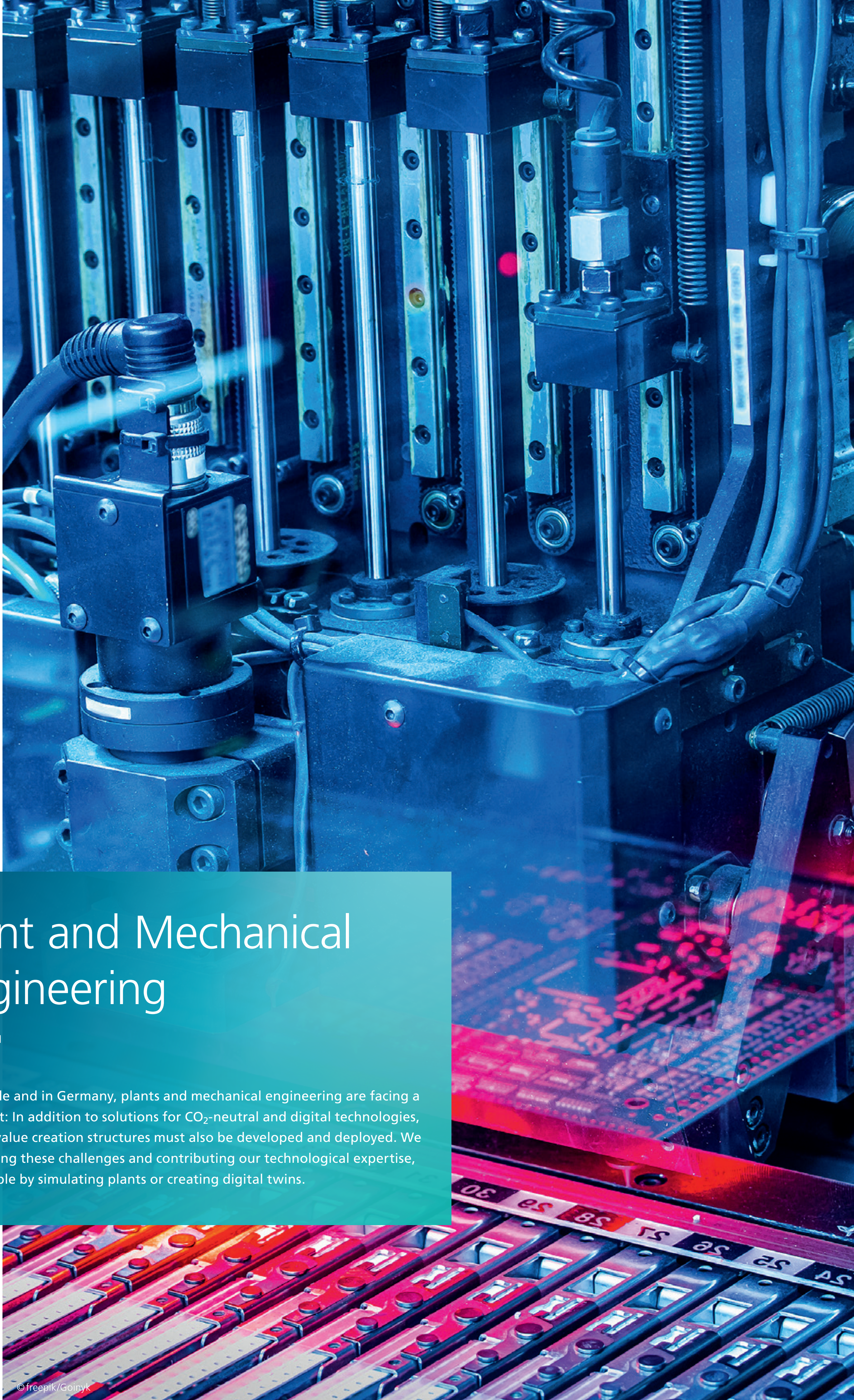


Plant and Mechanical Engineering

Worldwide and in Germany, plants and mechanical engineering are facing a major test: In addition to solutions for CO_2-neutral and digital technologies, resilient value creation structures must also be developed and deployed. We are meeting these challenges and contributing our technological expertise, for example by simulating plants or creating digital twins.

MESHFREE – Process Simulation to the Point

How does water behave when a car drives through a puddle? How efficient is a water jet turbine? What happens during machining or during the filling of a beer glass? These are all complex questions to which there is an innovative ITWM answer in the field of simulations: MESHFREE.

The interdisciplinary team around Dr. Jörg Kuhnert and Dr. Isabel Michel now consists of seven members and is developing meshfree simulation as a key solution for a wide variety of application fields. Their MESHFREE software combines more than 15 years of expertise from the Fraunhofer Institutes ITWM and SCAI.

Simulating dynamic processes

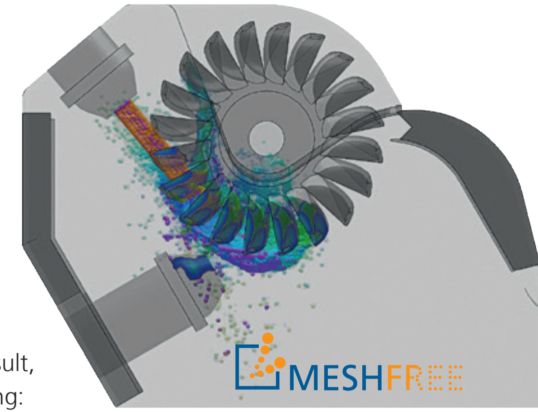
"For a long time, a computational grid was first placed over every geometry in the simulation process. This is and was usually expensive, tedious and also not optimal for many processes in terms of results," says Kuhnert. "Our simulation method eliminates the need for such computational grids. Instead, we use the finite pointset method (FPM) approach. This uses point clouds in which each point can be freely positioned." This offers decisive advantages over traditional methods and more and more cooperation partners are now taking notice.

"In the automotive sector, we have been providing support with simulations for some time now. MESHFREE makes processes more understandable digitally," explains Michel. Specifying material properties is sufficient to predict behavior with MESHFREE. The user exports the geometry from common CAD tools. "As we continue to develop our methodology, we work hand-in-hand with the industry. Examples include multiphase simulations or 3D-2D transitions. In the same way, we are exploring the interaction of fluids and solids. As a result, the demands on simulations are growing: MESHFREE is becoming more efficient and more accurate, and at the same time we want to make it easier to use. Smaller companies should also benefit from the solution."

New boost for turbines

One of these practical examples is hydropower turbines, or more precisely Pelton turbines. "In a project that we are implementing with Voith Hydro, among others, different model approaches are intertwined," Kuhnert reports. "We are investigating the water flow in interaction with the air as well as the behavior of the complete flow. Wear, known as abrasion, is also mapped by MESHFREE."

The example of abrasion illustrates how important simulations are because, above all, they can save time and money, Kuhnert emphasizes. "The surface of a turbine runner is damaged over time by sand or stone particles contained in the water. This leads to changes in the flow and the turbine becomes weaker. The runner will eventually need to be replaced," the team leader explained. "If modernization does occur, the team assists in optimizing the turbine," he continued. "Simulation is a great tool for predicting flow, the formation of water layers and material wear – in plant design even long before a prototype is built.



The simulation with MESHFREE shows the flow behavior and abrasion (wear) in a Pelton turbine.

Further information on the project page www.meshfree.eu

Contact

Dr. Isabel Michel
Department "Transport Processes"
Phone +49 631 31600-4667
isabel.michel@itwm.fraunhofer.de

Smart Monitoring, Automated Foresight

"Condition monitoring", permanent monitoring of the machine condition, and "predictive maintenance", machine-learning-based prediction on the basis of data – the team around Dr. Benjamin Adrian has built up expertise in these focal areas. Here, mathematics and AI provide tailored solutions. One practical example is the collaboration with Berger Holding (Memmingen Allgäu), where everything revolves around ball screws.

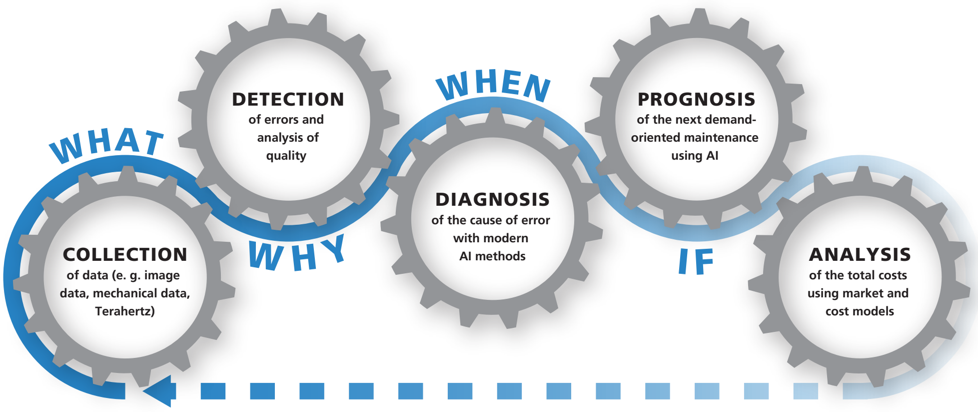
Predictive maintenance is the optimal maintenance strategy.

A ball screw is installed in machine tools, for example, and is used in the automotive industry, measurement technology, medicine, and aerospace. Large forces act on the component and the service life is related to the load on the balls. Maintenance and avoiding failures are production goals – preferably automated and smart.

In the project, this means proceeding step by step for the team: "Based on sensor data and their complex analysis, we calculate the profile, virtually the fingerprint of each ball screw in as-new condition," explains Adrian, project manager at the "System Analysis, Prognosis and Control" department. This profile serves as a reference. Ball screw operators can then perform comparative measurements or have them performed automatically and observe how the profile has changed. This data answers questions such as: Is the ball screw installed correctly? How does the condition change? When does the ball screw need to be replaced?

Goal: A ball screw that controls itself

"We are not just looking at data itself, but examining where it comes from. We want to understand exactly what the data is telling us and how it is created. Also with our experience around sensor technology." Based on this, the testing station and measurement technology are being expanded and a concept for moni-



Condition monitoring and predictive maintenance: data acquisition, analysis, prediction and evaluation from a single source.

“We will be able to improve our quality control through the cooperation with Fraunhofer ITWM and save our customers rejects and unplanned machine downtimes.”

Dr. Martin Körner
Development engineer at Berger Holding

Project example Berger: Digitization of a ball screw. A ball screw translates rotational motion into translational motion and vice versa.

toring is being developed (condition monitor). In Berger’s case, this now means its own software.

Berger is pushing ahead with this further development of ball screws as part of the “Pay-per-Stress” project sponsored by the German Federal Ministry for Economic Affairs and Energy. The goal is to introduce a new leasing model for machinery and equipment whose rates are calculated not only according to useful life, but also to actual wear and tear. This requires a reliable wear model for each critical machine component, such as the ball screw. This increases the transparency of costs and reduces risk surcharges in the leasing rate. This makes the concept equally attractive for small and medium-sized companies with limited financial resources. The end user also recognizes faulty assemblies or where problems need to be fixed and can look ahead to see when they need to renew or replace a part (predictive maintenance). Berger’s major goal is a ball screw that monitors its own wear.

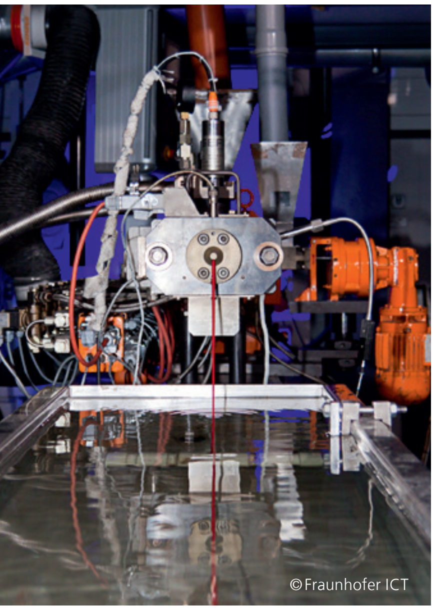
Further information on our website at www.itwm.fraunhofer.de/en/predictive-maintenance

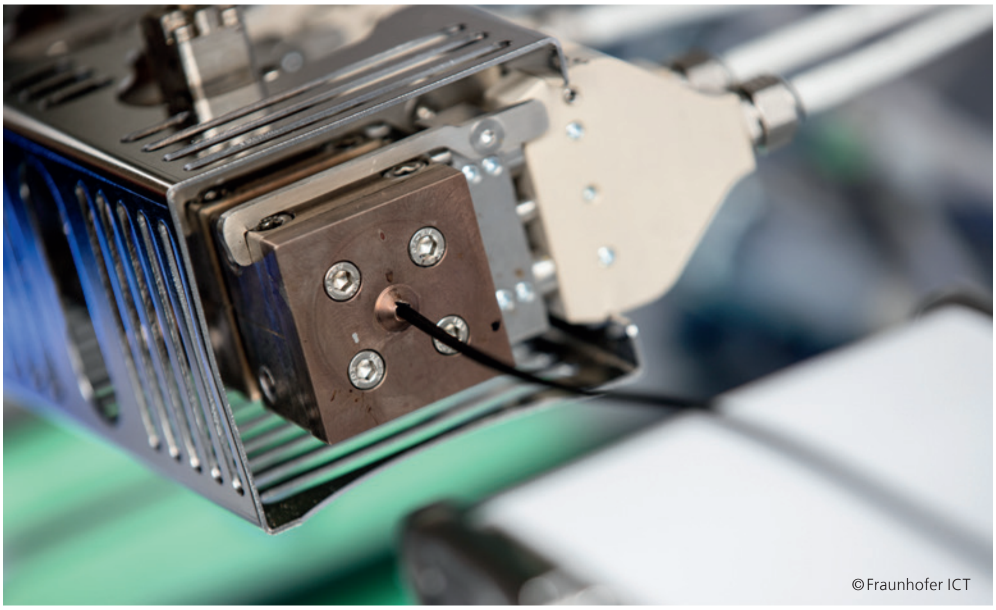
Contact

Dr. Benjamin Adrian
Department “System Analysis, Prognosis and Control”
Phone +49 631 31600-4943
benjamin.adrian@itwm.fraunhofer.de

Hybrid Backward Computing for the Plastics Industry

In the Fraunhofer-internal project HyTwin, the ITWM team around Dr. Alex Sarishvili is developing a hybrid digital twin together with researchers from the Fraunhofer Institute for Chemical Technology ICT. Using machine learning (ML) methods, this twin supports companies in the optimization and control of their plastics processing, more precisely their extrusion processes.





A test setup based on real production processes and equipped with extensive measurement technology is being created in the Fraunhofer ICT laboratory.

Extruder, additives, twin screw, nozzle – these are all technical terms from the world of plastics processing, although there are of course many complex variants of production. However, the extrusion process is common to all of them. Here, plastic is pressed as a tough mass under high pressure and high temperature through a shaping opening. At the end, the company receives as a product, for example, thermal insulation panels or plastic granulate for further processing into PET bottles or plastic pipes. "Extrusion is a highly complex physical-chemical process in which hundreds of parameters play a role and which is accordingly difficult to model and optimize," explains Sarishvili. Almost all plastics processed into a product pass through such a step in the process chain.

In the plastics industry, optimizing this still often means using "trial and error" to test how the quality of a product can be improved and optimized by varying individual parameters. Necessary material parameters are determined and tested anew for each material mixture of the real process. This is time-consuming and cost-intensive.

Fraunhofer ICT has a modern pilot plant with twin-screw extruders from 16 to 43 mm as well as versatile metering options at its disposal.

Smart modeled and calculated backwards

Computer simulations or digital twins offer the possibility of optimizing almost the entire extrusion process based on simulation. The project team is taking a hybrid approach: They are developing a digital twin that is both data-based and model-based, which uses AI to predict and optimize. In the best case, the digital twin thinks about the end first and calculates backwards: What product properties or quality do I want and what parameters do I have to set for this? Machine learning processes need masses of data if they are to function properly. At the beginning of the project, therefore, real test data was initially generated at Fraunhofer ICT. They are adapted to a physical-chemical process model and a data cloud of measurement and simulation data is generated. The AI then learns from this.

The expertise of the researchers at Fraunhofer ITWM lies particularly in mathematical modeling and simulation of technical processes. "For many years, (deep) machine learning methods have also been developed at our institute. We are responsible for smart algorithms," says Sarishvili. This has resulted, for example, in the Design for Quality Prediction software tool, which provides essential functions for creating simple data-based models for extrusion processes. As a result, the digital twin should then make it possible to achieve, among other things, higher production speeds, greater flexibility and higher product quality at the lowest possible cost. And not only that, at the end of the project, the goal is an easy-to-use software platform that can also be used by small and medium-sized enterprises (SMEs).

The team also has new projects lined up already: The ENERDIG project, promoted by the Federal State of Rhineland-Palatinate with funds from the European Fund for Regional Development (EFRE), just for starters. The focus here is on determining and optimizing the energy flexibility of extrusion processes.

More information on process analysis using machine learning at www.itwm.fraunhofer.de/process-analysis

Contact

Dr. Alex Sarishvili
Department "System Analysis, Prognosis and Control"
Phone +49 631 31600-4683
alex.sarishvili@itwm.fraunhofer.de

EMMA Learns to Drive – Dynamic Human Model for Autonomous Vehicles

5

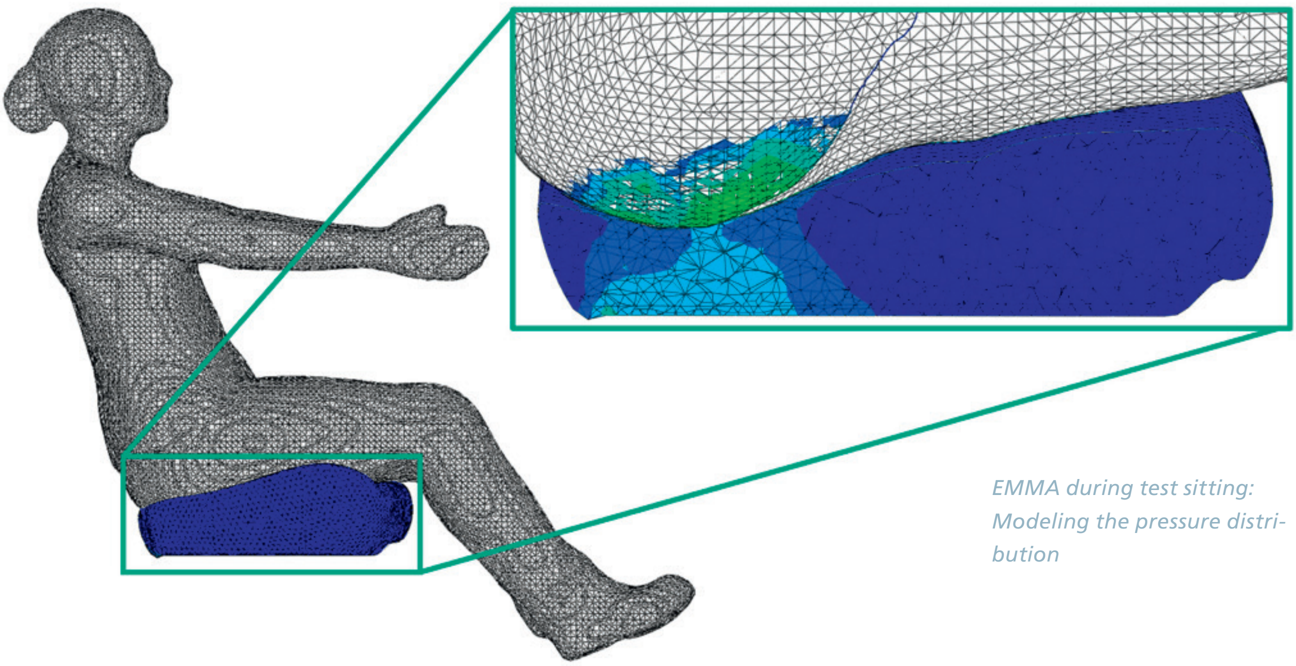
Five disciplines combined in EMMA4Drive: mechatronics, ergonomics, psychology, automotive engineering and techno-mathematics

In order to understand the expectations of customers of autonomous vehicles, to strengthen their trust and to prove safety, new digital tools are needed for research, development and validation of the technology. With the EMMA4Drive project, researchers in the division of "Mathematics for Vehicle Engineering" are further developing the dynamic human model EMMA-CC for use in fully or partially autonomous driving vehicles.

EMMA-CC stands for "Ergo-dynamic Moving Manikin with Cognitive Control" and is an old acquaintance: In the MAVO project of the same name, six Fraunhofer institutes had collaborated on digital human modeling for the simulation-based ergonomic design of workplaces. The further development EMMA4Drive now virtually takes a seat in the car and dynamically simulates the interaction of human body parts and the vehicle seat during driving maneuvers. The resulting software prototype will serve as a digital twin of the occupants, helping to analyze and evaluate new seating concepts in the passenger compartment in terms of safety and ergonomics during driving maneuvers.

Motion sequences instead of quasi-static tests

So far, human models have mostly been used in crash simulations to estimate the risk of injury. However, detailed, computationally time-intensive models for calculations in the millisecond range are used here, which are not suitable for the simulation of dynamic driving maneuvers, since longer processes have to be simulated here. Another field of application for digital human models are ergonomics analyses in assembly planning. The models used for this purpose often only represent postures of the human body or quasi-static motion sequences by means of highly simpli-



EMMA during test sitting: Modeling the pressure distribution

fied multi-body kinematics. Such models do not take dynamic effects into account and the analysis of physical loads is hardly possible, since pure kinematics models can provide little information about biomechanics..

Sit better, operate more comfortably

"Our human model, on the other hand, uses an optimization algorithm to automatically calculate new body postures and entire motion sequences over a longer time window with the associated muscle activities," explains project manager Dr. Marius Obentheuer. "This means that the simulation model can also be used to investigate the effect of dynamic driving maneuvers on humans and their (reaction) behavior – for example, in the design of assistance systems or control algorithms for (partially) autonomous driving." EMMA4Drive thus enables comparatively simple implementation of new movement patterns and efficient virtual investigation of safety, comfort and ergonomics in (partially) autonomous driving.

EMMA on RODOS®

And before EMMA is allowed on the road, she must of course pass her driving test – virtually in our interactive driving simulator RODOS® (RObot based Driving and Operation Simulator). But first, a real human takes a seat there to collect physical measurement data and provide input for the simulation software. The interaction between the driver and the seat is investigated, for example the pressure distribution. This data should help to better answer fundamental questions about autonomous or semi-autonomous driving: How quickly should the tilted backrest of a seat be raised again with the integrated electric motor system? Does the turned seat return to its original position? How long does it take for the human to take the wheel again when the vehicle signals "Danger from the right, please take over!" in semi-autonomous mode?

The driving simulator is a central component of the technical center in the division "Mathematics for Vehicle Development" and allows the use of different production cabs and real car bodies mounted on a strong robot arm. Currently, the researchers are working on a combined biomechanical-mechatronic model of the coupled seat system, which can be used to parameterize and calibrate the simulation software developed in the EMMA4Drive project.

Fewer hardware conversions required

This means that in the future, certain tests that are primarily aimed at physically stressing the occupants can also be carried out purely virtually, in addition to individual RODOS® simulator studies in a real driving cabin. When testing new concepts or comparative investigations of alternative variants, this saves time-consuming hardware modifications. However, for studies in which psychological aspects of the driving behavior are in the foreground, the simulation with RODOS® in a realistic cabin environment remains indispensable, since it is crucial for achieving a perfect immersion of the human being into the driving situation.

Further information can be found at www.itwm.fraunhofer.de/emma4drive_en

Precision work during the cabin change: For the next test cycle, a car chassis is lowered into the projection dome of the RODOS.

Contact

Dr.-Ing. Marius Obentheuer
Department "Mathematics for the digital factory"
Phone +49 631 31600-4766
marius.obentheuer@itwm.fraunhofer.de

Virtual Vision Is Better: New Approaches in Image Processing

What makes a good inspection system for the industrial production process? First and foremost, the lighting and camera setup, because depending on how the light beam falls on a surface, defects such as dents or scratches become more apparent. Of course, the properties of the material to be inspected also play a role. Plastic has a different optical behavior than metal.

Here you can clearly see that certain areas in the image are overexposed. Reliable defect detection is not possible there.

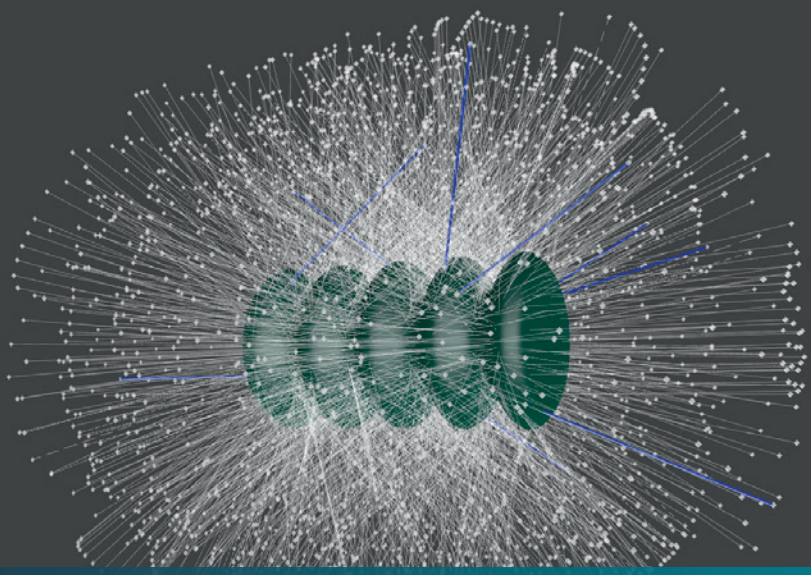
As long as the geometry of the test object is simple, such as rubber seals, tablets or metal plates, the setup can be adapted in just a few steps. The situation is quite different with complex geometries: If one takes, for example, a commercially available bulbous thermos made of aluminum with a handle made of plastic, it is almost impossible to develop a machine for fully automated inspection. If a robot is used to precisely maintain the angle between the surface and the illumination, this fails at the handle at the latest. In addition, aluminum and plastic exhibit different reflective behaviors. The angle of the illumination and camera must therefore be changed during the inspection.

Image processing, computer graphics, robotics: Together to the goal

So what to do? One solution would be to construct the entire inspection in the computer and physically simulate it – in other words, virtual image processing. Interdisciplinary work is being done on this at the Department of Computer Science at the TU Kaiserslautern and at Fraunhofer ITWM: Using existing computer graphics methods such as ray tracing, material models, CAD, and camera models, the team generates synthetic images and tests image processing algorithms on them. In addition, it implements methods to determine the optimal positions of the camera and lighting.

The first research result is an algorithm that calculates which surface areas can be safely inspected at all. For this purpose, it uses a 3D model of the test specimen and takes into account camera positions and illumination angles. This also resulted in a demonstrator consisting of a robot with camera and illumination.

However, simulating an entire inspection system and then modeling its effectiveness is a much more complex task. That is why the researchers asked themselves: How do you calculate optimal camera or illumination positions in relation to the inspection object? And they were able to answer it in part – with another algorithm. This method uses the 3D model to scan the entire surface and uses the local curvature to calculate which surface points are



Based on the geometry of the inspected object, our software creates a list of viewpoint candidates (white) and reduces them to a set of viewpoints needed to cover the most important areas (blue). A viewpoint marks a physical point in space, relative to the object, where the camera must be positioned during the inspection.

"In addition to computer graphics and visualization, we also need modeling based on physical principles for a viable simulation. With the V-POI planning tool, we are taking a big step in this direction"

Prof. Hans Hagen
Department of Computer Science at the TU Kaiserslautern

potentially important and thus must be in the camera's field of view. These positions are used for path planning of the robot or even fixed camera positions.

Learning system: Viewpoint of interest V-POI

The V-POI planning tool developed by the project team already copes well with component geometry and surface properties and has also learned to recognize potential problem areas during analysis. In order for the inspection system to know what a good part should look like, it is first "fed" the CAD data of a workpiece. The software is designed to calculate individual scan paths for objects placed on a turntable, for example, based on the specific product.

Goal: Manufacturer-independent system

The research objective is a software infrastructure that simulates the complete inspection environment, i.e. both the properties of the test specimen and the properties of all hardware components (illumination, camera, optics, etc.). The architecture of the software is to be designed in such a way that commercial suppliers of sensors, lighting, etc. can enter their product-specific properties, e.g. camera parameters, without having to disclose sensitive know-how. The system will therefore be manufacturer-independent.

Further information at
www.itwm.fraunhofer.de/virtual-inspection-planning

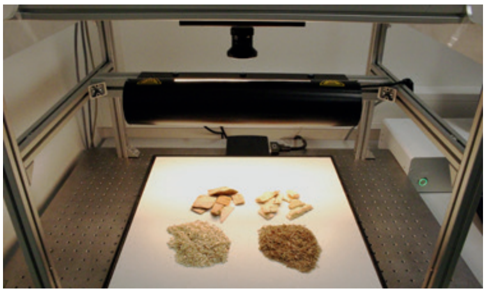
Contact

Dipl.-Inf. Markus Rauhut
Head of department "Image Processing"
Phone +49 631 31600-4595
markus.rauhut@itwm.fraunhofer.de

RGB Becomes Hyperspectral: Seeing More Than the Eye Allows

The monitoring of individual steps and parameters in production has been advanced with a great deal of energy for years in the context of "Industry 4.0". Through the development of new, efficient sensors and measuring systems, data is collected, evaluated and used to optimize production. In the field of optical sensor technology, hyperspectral imaging is an important building block for capturing information that initially remains hidden to the eye.

Hyperspectral image data in the infrared wavelength range can be used, for example, to identify wood species in production in real time, thus ensuring the correct composition, and ultimately quality, of the products. One important application is chipboard production.



Hyperspectral camera with illumination unit: The camera captures the wood samples as if on an assembly line – up to 300 line images per second.

It is all in the mix – even with chipboard

The composition of the processed wood chips plays a crucial role in the strength of the boards. Hardwoods such as beech and oak form the basis, but are also more expensive than softwoods such as pine and spruce: The right mix between hardwood and low-cost softwood is therefore crucial for efficient chipboard production.

With hyperspectral imaging, the spectral information of the wood chips on the conveyor belt is recorded via a line scan in the near-infrared range between 1000 nm and 2500 nm wavelength – with up to 300 measurements per second! These images contain the complete spectral information at each pixel. Due to small but measurable differences in the response of the various woods, these are assigned to the wood types in real time after a one-time learning process. This works because the measurement data is assigned to individual classes after processing and data reduction. Various classifiers are available for this purpose in order to react flexibly to specific applications. In the example, the correct assignment succeeds in over 95 percent of cases.

Much more than just wood detection

The method is not only suitable for wood species identification, but can also detect foreign substances in piles, determine the degree of ripeness of fruits and vegetables, or be used for sorting different materials. Depending on the application, the measurement principle including hardware and software is adaptable for different scenarios.

More info at www.itwm.fraunhofer.de/optical-metrology

Contact

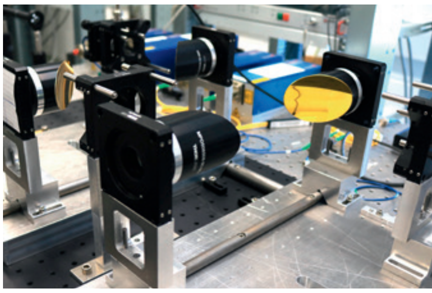
Dr. Stefan Weber
Department "Material Characterization and Testing"
Phone +49 631 31600-4924
stefan.weber@itwm.fraunhofer.de

TeraSpect for Multispectral Measurements

Together with the industrial partner TOPTICA Photonics AG, Fraunhofer ITWM and Goethe University, Frankfurt am Main, have combined two successful technologies of terahertz measurement technology into a new measurement principle: the terahertz spectroscopy system TeraSpect.

Transistors from standard processes in the semiconductor industry can be used as highly sensitive terahertz detectors over a wide frequency range. If a series of these detectors is specifically optimized for several individual frequencies, which are then referred to as resonant detectors, these individual frequencies can be effectively filtered out from a broadband terahertz radiation source. So-called "spectral fingerprints" can then be measured. These are characteristic absorption lines that can be used to uniquely identify materials.

The system can be used, among other things, for authenticity testing in goods inspection.



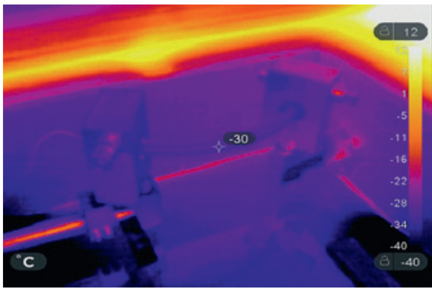
The TeraSpect system enables fast multispectral terahertz measurements.

More informations at www.itwm.fraunhofer.de/teraspect-pm

New Features for MeSOMICS®

It looks simple, but it has what it takes: the highly automated MeSOMICS® measuring machine, designed and constructed in the division Mathematics for Vehicle Engineering. MeSOMICS® stands for "Measurement System for the Optically Monitored Identification of Cable Stiffnesses" and supports the IPS Cable Simulation product family. This software simulates and optimizes the routing of cables and hoses, especially in the confined installation spaces of modern vehicles. To ensure that the simulation is as realistic as possible, the mechanical properties of the individual cables must be determined. Especially important here are bending and torsional stiffnesses. With MeSOMICS® even the users of the IPS software can quickly and easily determine the required parameters themselves: The desired data sets are available in just three hours and are used for the numerical simulation in IPS Cable Simulation.

But MeSOMICS® can do even more: namely measure test specimens under pressure (up to 1000 bar) and ambient temperatures between -30°C and 130°C. "These options have been increasingly requested by our customers. Now we can offer them as a service in our Technical Center," says its head Dr.-Ing. Michael Kleer with great satisfaction.



A thermal imaging camera checks the temperature of the test specimen in the MeSOMICS climate chamber.

Further information at www.mesomics.eu