
Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB

**Annual report 2021/2022**

# From idea to implementation: We make AI fly

www.iosb.fraunhofer.de

*We bring artificial intelligence to real-world applications – for example, in the field of embodied AI. Our robot dog Friedbert and our excavator ALICE (acronym for „Autonomous large intelligent crawler excavator") are able to autonomously explore hazardous environments and carry out earthworks. This makes it possible to remediate contaminated sites without humans having to enter the danger zone. As an overlay, the photo shows the digital environmental representation that the mobile systems compute from sensor data for autonomous navigation and manipulation.*

## We make AI fly

Artificial Intelligence – there is probably no other field of technology that is currently associated with so many hopes for innovations, new business models, growth opportunities and disruption. For Germany alone, its economic potential for the coming years is estimated at several hundred billion euros. We are experiencing huge changes to our living and working environments associated with AI, with more to come in the future.

But the challenges of turning all of these visions into reality are also enormous. Artificial intelligence now produces eloquent-sounding texts, fakes deceptively real-looking videos and can even beat world champions at complex board games. Some practical digital tools that are now part of everyday life, such as speech recognition on smartphones, were only possible in the first place thanks to AI. However, progress is more arduous in many sectors. Where AI is just one component in a complex system, where something is at stake, where systems interact with the physical world in ways that could break things or even endanger people, the successful application of AI still faces major challenges, some of which are very fundamental.

For us at Fraunhofer IOSB, researching AI applications is a part of our DNA, not only since the hype of the last few years, and we certainly do not limit ourselves to the commonly referenced subfield of deep neural learning. Whether it is logical reasoning, solution seeking, environmental perception, understanding and modeling, motion planning or making the best decisions in the face of uncertainty – our focus is diversified. We are also familiar with important application domains, as our research and development – which is not just limited to the field of AI – is focused on practical issues from sectors such as industrial production, mobile systems, human-machine interaction, testing and sorting tasks, public safety or utility infrastructure management.

Making AI fly in these domains too, through appropriate methods and tools – that is our strength. This is our mission. It is a common thread across the many activities and focuses of our institute. It is therefore also a theme that runs through this Annual Report and turns up in many chapters.

**1** According to market research studies published by PwC and eco/Arthur D. Little in 2018 and 2020, the potential effects on the German GDP amount to 430 and 480 billion euros, respectively (see https://www.pwc.de/de/digitale-transformation/business-analytics/kuenstliche-intelligenz-sorgt-fuer-wachstumsschub.html and http://go.eco.de/ki-studie2019).

# Preface

**Dear reader,**

Welcome to this edition of the Fraunhofer IOSB annual report, which is quite special in some respects: It is – after the 10th anniversary of our merger into Fraunhofer IOSB in 2020 – the first report in the second decade of our institute's existence. It is also our first report based on the updated Fraunhofer corporate design. This has given us the opportunity to sharpen the editorial profile of this publication and, in particular, to formulate a cover statement that is echoed at many points throughout the report: "Making AI fly" alludes to the topic of AI Systems Engineering, which has developed into an increasingly important theme that connects the institute's different units and many of its activities.

**Coronavirus: Hybrid work and gratifyingly few problems**
Furthermore, this report is our first public stocktaking since coronavirus made its mark on the world – and thus also on the world of work. Almost immediately after we published our anniversary annual report on the occasion of our anniversary event at the beginning of March 2020, the pandemic emerged and brought a lockdown, a widespread shift to home offices and an accompanying surge in the digitization of everyday processes. With its two-year reporting period, this edition covers precisely the peak phase of the pandemic.

For us at Fraunhofer IOSB, coronavirus has also brought about rapid changes that were difficult to imagine beforehand. Fortunately, however, the situation proved to be manageable, not least thanks to our employees, who were as committed as they were responsible: We were affected by infections to a below-average extent. Work continued with few restrictions, and we were able to parry the economic risks associated with the pandemic. New Work, or hybrid working, turned out to be a fundamentally viable model. As a result, we are aiming for a "new normal" in this regard for the post-pandemic period.

Yet, however successful digital collaboration may be, we still look forward to being able to attend face-to-face meetings again soon without restrictions. Despite all the advantages of digital meetings, we still consider personal encounters with our customers from industry and public authorities as well as our project partners to be necessary to establish and maintain lasting and sustainable collaborations.

**New sites and a new research factory**
Apart from coronavirus and its impacts, the past two years have also brought changes for our institute. While the business figures continued their steady upward trend (cf. p. 21), the number of our sites took an unusual leap upward. With Rostock (focus: smart ocean technologies), Berlin (focus: simulations to improve the safety of socio-technical systems) and, in the future, Oberkochen (focus: active laser fibers in the wavelength range >1.6 µm), three new sites with independent scientific activities are being established. This is not because we are striving for geographical expansion per se. At each of these sites, however, special constellations for cooperation have arisen, which present unique opportunities in the sense of the Fraunhofer model.

In addition, the Karlsruher Forschungsfabrik (Karlsruhe research factory), the conception and development of which has kept us busy for a long time, was finally completed and officially opened. This provides our customers and us with a new development and demonstration center dedicated to the industrial production of the future – in addition to the already established SmartFactoryOWL in Lemgo. You can read more about all these (and other) developments in the Highlights chapter starting on p. 6.

**Technology development program: A successful funding instrument**
It is with some pride that we look back on how our main internal institute funding instrument for pre-competitive research has evolved. In 2019, we launched our annual internal Technology Development Program (TEP) call for proposals. The business units can apply with ideas for cross-departmental projects. These ideas must be of substantial scope and suitable for advancing the business unit strategically, ultimately providing competitive advantages for our customers in industry and government. TEP funding represents a significant proportion of our basic funding.

Three funding periods have now been completed (with some projects receiving funding for two or even three years in succession), and a number of success stories have developed in this way. You can read about some of them in the business unit chapter of this report. Examples include our

semi-autonomous survey system for rivers and lakes, the utilization of light field technology and AutoInspect, a system for comprehensive, automated, multisensory inspection that also integrates manual inspection by human operators and combines all the results into a single digital quality twin.

We are equally proud of our leading role in a large number of publicly funded major research and development projects such as the Competence Center for AI Systems Engineering CC-KING, the Competence Center Robotic Systems for Decontamination in Hostile Environments ROBDEKON, the AI Living Lab for Industrial Production, the European defense research project OCEAN2020 and the Bauhaus.MobilityLab. This report will also go into more detail on these and other projects.

Of course, all these pre-competitive and publicly funded research activities ultimately have one goal – otherwise we would not be Fraunhofer: They are intended to help transform scientific knowledge into practical applications, in projects for and with our customers, and to pave the way for technological innovations that generate tangible added value and competitive advantages. This is our mission at Fraunhofer, and with this goal in mind, we would also like to put our expertise and knowledge at your service. Therefore, if you work for an authority, company or other organization whose challenges we could help solve with our competences – please do not hesitate to contact us!

Sincerely,

Prof. Dr.-Ing. habil. Jürgen Beyerer
Head of Fraunhofer IOSB

# Contents

# Highlights

## 1. Making AI fly

**AI Systems Engineering**
To systematically and reliably bring artificial intelligence processes into productive use – in areas where more is at stake than, for example, speech recognition on cell phones or the automatic categorization of vacation photos: this is what AI Systems Engineering is all about. The topic is a common thread throughout a large number of Fraunhofer IOSB's activities and can be viewed as a research program or even a new discipline that forms a bridge between the domains of data scientists and AI specialists, engineers and computer scientists, which were previously largely separate.

The vision of AI Systems Engineering is to provide engineers with easy to handle, well-defined tools that harness the potential of AI as part of complex systems and enable predictions to be made about their performance at the time of design. This could prove a breakthrough for the use of AI in application domains such as industrial production or mobility. In such areas, AI has so far mostly been used in the context of costly research projects. Success or failure is only determined in retrospect, moreover, the results often do not go beyond the status of a proof-of-principle demonstrator, because real productive operation poses completely new challenges in terms of acceptance, commissioning, robustness and maintainability.

**Competence Center Karlsruhe for AI Systems Engineering CC-KING**
The Competence Center Karlsruhe CC-KING, which was launched in 2020 and is coordinated by Fraunhofer IOSB, is specifically dedicated to meeting this objective. Partners in the project, which is being funded by the Baden-Württemberg Ministry of Economic Affairs, Labor and Tourism with an initial sum of 3 million euros, are the FZI Research Center for Information Technology and the Karlsruhe Institute of Technology (KIT). At CC-KING, work is being done on fundamental issues of AI Systems Engineering; in particular a comprehensive process model for AI Systems Engineering has been created with PAISE®. PAISE describes the phases, challenges and roles in the development and operation of AI components as a part of complex systems, and therefore also enables a systematic approach in larger, interdisciplinary teams. Suitable tools for individual phases – e.g. for data preparation and explainability of AI – are developed and provided at CC-KING.

From the beginning, a main focus of CC-KING has been implementing AI in specific applications in the fields of production and mobility. Small and medium-sized enterprises, large corporations and multiplier organizations are closely involved in the further development of the overall strategy via the Innovation Advisory Board, and there are also concrete subsidized support services for interested companies. To date, in 15 QuickChecks, concrete potential applications of AI have been explored; in a series of TransferChecks, solutions are being developed for sustainable practical use – for example, in concrete component production plants or in decision support to operate streetcars as optimally as possible on a wye track. With several AI Engineering Days in 2022, the Competence Center will provide public forums to discuss and disseminate the topic.

**ML4P – Machine Learning for Production**
Important preliminary work and specifications regarding the use of AI processes in industrial production were carried out as part of the Fraunhofer ML4P lighthouse project. In this Fraunhofer IOSB-led joint project, which was successfully completed in 2022, six Fraunhofer Institutes systematically addressed the challenges and potentials of using machine learning methods in production for the first time over a period of four years. The goal was and is to use the extensive data that is practically always generated in modern plants (and which can also be obtained from older machines by using sensors that can easily be retrofitted) to perform predictive maintenance on machines, to make the production process faster, more energy-efficient and more resource-efficient and to increase product quality.

To this end, a process model has also been developed as part of the ML4P project, which ML experts use to work alongside companies on a methodical and step-by-step basis, first to develop a concept and to check its business validity. Specifications are then defined, before the system is implemented,

**The aim of AI Systems Engineering is to develop AI and ML for use in engineering, in a similar way to classical engineering,«**

**says Prof. Jürgen Beyerer,**
Head of institute


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QuickChecks performed at CC-KING

**Websites**

www.ki-engineering.eu
www.iosb.fraunhofer.de/ml4p


**With the Karlsruhe Research Factory, Fraunhofer and KIT are making a significant contribution, which consolidates Germany's leading position as an industrial hub,«**

**says Prof. Dr.-Ing. habil. Reimund Neugebauer,**
President of the Fraunhofer-Gesellschaft

tested and finally transferred to permanent everyday operation. Although data clearly plays a central role here, the knowledge of the process experts is also integrated into the resulting ML model. For these process phases, the associated ML4P software suite provides the crucial tools – which, wherever possible, rely on established and open standards and interfaces. The concept was tested and validated in various application domains at the partner institutes.

**Karlsruhe Research Factory for AI-integrated Production**
The "Karlsruher Forschungsfabrik" has gone into operation as a new laboratory for digitalization and AI Systems Engineering in industry following a lengthy planning and construction phase – and it is located just a few minutes by bike from Fraunhofer IOSB's Karlsruhe location. "Optimize established processes – upgrade unrefined processes" – this is the mission that the Research Factory partners Fraunhofer IOSB, Fraunhofer Institute for Chemical Technology ICT and the wbk Institute of Production Science at the Karlsruhe Institute of Technology (KIT) are tackling together with partners in industry.

The idea: By "over-instrumenting" with sensors and actuators, new production processes that are not yet properly understood are to be explored. Based on the accumulated data, machine learning can learn on the fly which parameters produce good results and thus optimize the process. As a result, high-quality products can be manufactured quickly and time-to-market can be shortened drastically.

This approach is also already being pursued in existing research projects. Now, however, the Karlsruhe Research Factory provides the ideal infrastructure for practical projects. On account of the total area of around 5000 square meters, industrial partners can now even set up real production facilities within the Research Factory and rapidly advance process development with the help of existing technical infrastructure (sensor technology, computer center) and in the creative team environment of a research institute. The possibilities for cooperation range from the classic collaborative research project to "Industry on Campus" and "Embedded scientists" (company employees working and performing research in the Research Factory).

**AI Living Laboratory**
Another lighthouse project around the harnessing of AI methods for data-driven industrial production or industrial data economy is the AI Living Laboratory, funded by the German

*Development and demonstration centers for the production of the future: Karlsruher Forschungsfabrik (left) and SmartFactoryOWL.*

Federal Ministry of Economic Affairs and Climate Action. Led by Fraunhofer IOSB-INA in Lemgo, it aims to create an open data platform for the application of AI in Industrie 4.0, which relies on open standards such as the Asset Administration Shell (AAS). The AI Living Laboratory brings together companies, AI experts and researchers in a safe environment and creates added value for all parties. Some parties can bring in real-world use cases and challenges for which they need solutions. Others get the data sets they need to (further) develop ML-based solutions. Based on case studies from operational practice, the success story of AI in production can be fleshed out, retold and communicated to new target groups.

As such, the AI Living Laboratory is not just a virtual network. Rather, it is closely interlinked with the Industrie 4.0 development and demonstration center SmartFactoryOWL and enables tangible collaborations in the real world. At the end of 2021, for example, a production line for sustainable coffee cups moved into the SmartFactoryOWL and is now becoming a test case for AI-optimized production of the future (see p. 75).

**ROBDEKON Competence Center**

Here too, the potentials of AI are systematically leveraged – except in this case we are talking about embodied AI, namely "robotic systems for decontamination in hazardous environments": In ROBDEKON, autonomous and semi-autonomous robot systems are being researched specifically for use in the dismantling of nuclear facilities, in the decontamination of plant components and in the remediation of landfills and contaminated sites. This is so that, in the future, people can stay away from the danger zone while this work is being carried out.

Fraunhofer IOSB contributes its expertise in sensor technology, environmental sensing, navigation over unstructured terrain and autonomous manipulation, for example. These are incorporated into the autonomy kits developed in Ilmenau and Karlsruhe, which can be used to convert near-series construction machines into (partially) autonomous robots. For example, during the positive regular evaluation in 2021, there was a live demonstration of how a driverless 24-ton excavator autonomously removes layers of soil and loads them onto the trailer of a tractor that also operates autonomously.

Preparations are now underway for a continuation of the competence center's initial four-year term. Launched in 2018, ROBDEKON was initially funded with 12 million euros by the German Federal Ministry of Education and Research as part of the "Research for civil security" program. The coordinator is Fraunhofer IOSB, where the ROBDEKON coordination office is also located. The Karlsruhe Institute of Technology (KIT), the German Research Center for Artificial Intelligence (DFKI) Bremen, the FZI Research Center for Information Technology and a number of industry and application partners are involved.

**Websites**

www.karlsruher-forschungsfabrik.de
www.ki-reallabor.de
www.robdekon.de


*The Quantum System One with 27 qubits was inaugurated as Europe's most powerful quantum computer by Fraunhofer and IBM in 2021.*

# 2. Other initiatives and infrastructures

**Karlsruhe Competence Center for Applied Security Technology (KASTEL)**
Back in 2011, KASTEL was initiated by the German Federal Ministry of Education and Research as one of three German competence centers for cybersecurity. After two temporary funding phases, KASTEL has now been made permanent in the context of the specially founded Institute for Information Security and Dependability at the Karlsruhe Institute of Technology (KIT). Under the motto "Traceable security in the networked world", KASTEL is working, among other things, on comprehensive security concepts for the area of critical infrastructures as well as on the quantification of security. Fraunhofer IOSB, with its expertise in industrial cybersecurity, continues to be closely involved in KASTEL through Prof. Beyerer's chair and heads the "Production" laboratory.

**QAPPS Center for Applied Quantum Computing Saxony**
Quantum computers are considered one of the key technologies of the future. The inauguration of the first IBM Quantum System One quantum computer in Germany by Fraunhofer and IBM in 2021 caused quite a stir – with 27 qubits, it is the most powerful system in Europe at present. This computer can be used to realistically test possible applications and build up crucial skills for the future. Fraunhofer IOSB is also participating in these opportunities.

The Cognitive Energy Systems department (KES) has already conducted initial trials on the Q System One with computational processes for the smart charging of large electric vehicle fleets. And with the Center for Applied Quantum Computing Saxony QAPPS, Prof. Dr.-Ing. Jörg Lässig, head of the Görlitz branch lab of Fraunhofer IOSB-AST, is building a long-term competence network. The initiative, which is funded by the Free State of Saxony and whose spokesperson is Prof. Lässig, also includes the Fraunhofer Institute for Machine Tools and Forming Technology IWU, the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS and the Fraunhofer Institute for Integrated Circuits IIS. In addition, the Technical University of Dresden and the University of Leipzig are representatives of more basic research and corresponding academic training.

The application areas QAPPS intends to focus on are simulation, machine learning and optimization – areas where the consortium sees there being high potential for quantum supremacy. The members want to develop pilot solutions by analyzing their challenges and application scenarios together with partners from industry, implementing suitable algorithms and evaluating them.

*In the NeoUVDes joint research project, Fraunhofer IOSB-AST is developing a system for disinfecting incubators for premature babies by means of UVC radiation.*

## UVC disinfection

From physics-based simulation to prototype implementation and characterization: 3 questions for Thomas Westerhoff on a booming theme

**Mr. Westerhoff, the coronavirus pandemic has hit home the importance of hygiene. How does UVC radiation make an impact in this area?**

Radiation with UVC light, which is made up of particularly short waves, has been proven to be an effective means of inactivating germs. However, safe disinfection means ensuring that people are reliably kept away from the source of radiation. Furthermore, the radiation dose must be sufficient for every surface area, or everywhere in the liquid or gas be disinfected. We have made it our mission to meet these requirements with cost-efficient solutions. In doing so, we are focusing on UVC LEDs as particularly flexible light sources.

**How can Fraunhofer IOSB contribute to this purpose?**

By doing what we do best – by combining technological and scientific expertise from disciplines ranging from physics and engineering to informatics to drive practical innovations. In specific terms, we simulate the propagation of the radiation and, if required, the flow conditions to calculate the incoming radiation dose. By combining this result with the spectrum of UV efficacy of individual microorganisms, we are able to very precisely derive the microbiological effect of the radiation. We are designing suitable light geometries and arrangements as well as developing LED control electronics and cooling concepts. Thanks to funding from the German state of Thuringia, we are also currently building a reference laboratory to thoroughly evaluate all possible UV devices from a technical perspective. A lot has been reported on the UVC disinfection of ambulances when they are not transporting patients (p. 68).

**Can you name other application examples?**

Whether you want to disinfect the cell phones of medical personnel, incubators for premature babies, water directly in the faucet, air in air purifiers or even in refrigeration units designed to keep food fresh on long journeys: The list of potential applications is long. As part of the Fraunhofer MobDi – Mobile disinfection project we have developed a module for mobile robots that can disinfect door handles or light switches fully automatically. By combining our technological skills with the expertise of microbiologists and companies providing the specific applications in question, we are able to produce promising solutions.

# 3. Locations and buildings

**Rostock location**
New application and synergy-oriented collaborations have led to three new entries being added to the list of Fraunhofer IOSB research locations. In Rostock, the cross-institute Fraunhofer research group Smart Ocean Technologies (SOT) was launched as part of the newly emerging Ocean Technology Campus in 2020. The goal of the interdisciplinary group is to develop future-oriented underwater technologies for sustainable use of the oceans. Having Fraunhofer's Digital Ocean Lab as a nearby, extensively equipped underwater test field in the Baltic Sea enables particularly practice-oriented research and development for this.

*Rostock's cargo and fishing port is where the SOT research group has its offices.*

Both the Karlsruhe location and the institute branch of IOSB at Ilmenau have sent scientists to Rostock. The Fraunhofer Institute for Computer Graphics Research IGD, the Fraunhofer Institute for Large Structures in Production Engineering IGP and the Fraunhofer Institute for Ceramic Technologies and Systems IKTS are also participating. Current developments include solutions for underwater inspection and maintenance, smart coatings for structural health monitoring and methods for analyzing and filtering microplastics in the oceans.

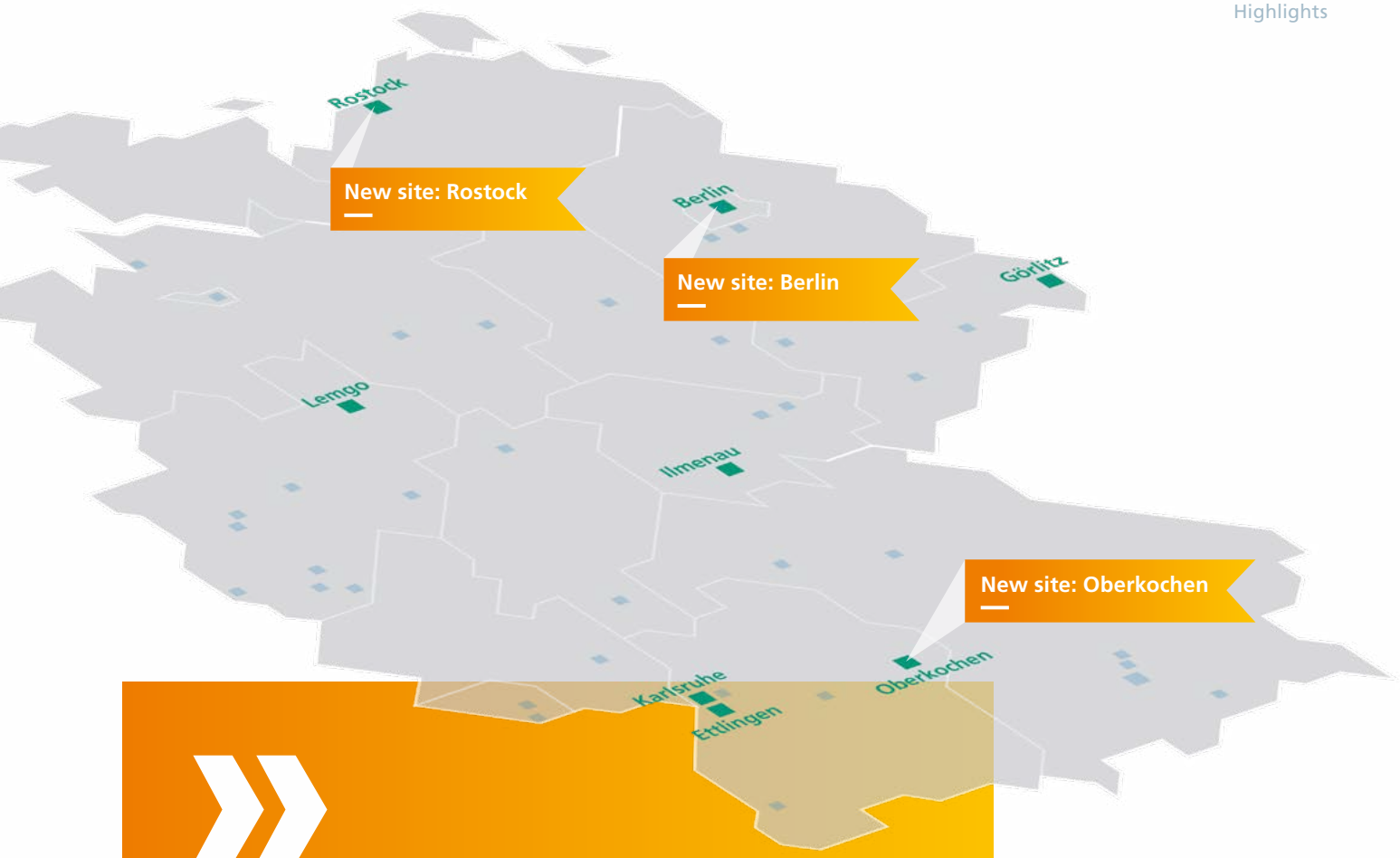
**Berlin location**
A similar cross-institute expertise pool will be created by the Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS in Berlin, which will start in 2022. The focus will be on public security: SIRIOS creates a unique research, testing and training environment for coupled simulations of complex security scenarios such as natural disasters or attacks. Within the framework of SIRIOS, such scenarios will be experienced and controlled through simulations in order to ultimately increase security and resilience in society.

Among other things, Fraunhofer IOSB and its institute branch IOSB-AST are contributing their expertise and experience in intelligent, privacy-respecting video surveillance, geo-information systems and situational awareness, as well as in the digitalization and cybersecurity of utility infrastructures. The Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, the Fraunhofer Institute for Open Communication Systems FOKUS and the Fraunhofer Institute for Transportation and Infrastructure Systems IVI are also involved in SIRIOS.

**Oberkochen branch lab**
A third new Fraunhofer IOSB location is being built on the Swabian Jura – in the immediate vicinity of relevant industrial partners and close to Aalen University of Applied Sciences, for which one of the focal points is the field of optical engineering/photonics. The plan is to establish a branch lab of the laser technology department (LAS) with generous support from the city of Oberkochen. There, a new research group will work on active laser fibers in the wavelength range greater than 1.6 µm and, in particular, will research and develop suitable fiber preforms and adapted fiber drawing processes.

Fraunhofer IOSB is therefore closing a gap in the value chain with regard to infrared lasers and in the future can help Germany achieve technological sovereignty in lasers of this wavelength range, which are important for optronic applications. Thanks to the city's intermediation, the new branch lab will reside in a new research and development campus belonging to HENSOLDT Optronics, which will be built by 2024. This has the considerable advantage that structural requirements for the planned research roadmap – in particular a tower shaft spanning several floors, required for the fiber drawing plant – can be implemented as desired.

**New construction in Ettlingen**
There is also news about existing locations, however. Having presented the new institute buildings for the AST and INA institute branches in Ilmenau and Lemgo in the previous Annual Report, this time we can report on structural changes in Ettlingen. In 2021, a container building was completed; it provides office and laboratory space that is needed at short notice for the young and rapidly growing laser technology department (see also chapter LAS, p. 56). Meanwhile, progress has also been made on plans for a permanent extension, which will replace the existing workshop building. Among




**With the new Oberkochen branch lab, we as Fraunhofer IOSB will cover the entire value chain for laser components in the >1.6 µm range,«**

**says Prof. Dr. rer. nat. Marc Eichhorn**
Director Fraunhofer IOSB Ettlingen

**+3**
new entries on the location map

other things, a tunnel and a crystal growing laboratory are planned here, as well as an indoor laser test track more than 250 meters long, which connects the new and the old buildings and can be used by a number of new laser laboratories. The building contractor is the Federal Republic of Germany, which owns the entire Ettlingen property.

**Karlsruhe Research Campus**
The plans for a new building on the Karlsruhe Institute grounds, essentially in the area of the current gateway and parking lot, have also taken on a more concrete form. The Fraunhofer Institute for Systems and Innovation Research ISI will move into the resulting "Karlsruhe Research Campus", too. The ISI has clearly outgrown its current building in the Waldstadt district of Karlsruhe. The second institute building on the current IOSB site will provide an additional 7500 square meters of usable space: 3900 square meters for Fraunhofer ISI, with the remainder being split into new office and experimental spaces for Fraunhofer IOSB and common areas.

Regarding research topics, there is a common vision linked to the forthcoming immediate neighborhood: to responsibly shape the development of AI and autonomous systems. The opportunity to combine our technological with ISI's social science expertise is a perfect fit for a topic with such a high impact potential. This will enable us to take a holistic view that integrates aspects such as the regulation and control of AI, but also participation and acceptance. The new building has now been approved and the next planning steps in collaboration with Fraunhofer ISI have begun.


## A young institute with a long history – 10 years of Fraunhofer IOSB

On March 6, 2020, shortly before the first Covid-19 lockdown but while special hygiene regulations were already in force, Fraunhofer IOSB celebrated its first double-digit birthday as an institute. The celebration in the media theater of the ZKM (Karlsruhe Center for Art and Media) was attended by around 180 of the institute's friends and supporters from the worlds of politics, business and science. Among others, representatives from the Federal Ministry of Defense and the Federal Ministry of Research, the Baden-Württemberg Ministry of Economic Affairs and the mayors of Karlsruhe and Ettlingen gave speeches conveying their congratulations.

Under the motto "Digitalization: What remains the same? What's next?", the focus was on future challenges in the fields of optronics, systems technology and image evaluation. Experts from the worlds of business and science addressed this topic in presentations and a panel discussion led by TV presenter Kristina zur Mühlen.

Video footage and other information about the celebration:

**www.iosb.fraunhofer.de/10-years**


*While digital events such as Fraunhofer's "Solution Days" (left) played an important role in 2020 and 2021, more in-person events have become possible lately. One prominent example was the ceremonial opening of Karlsruher Forschungsfabrik. The photo shows how Prof. Beyerer (right) gave State Premier Winfried Kretschmann a tour of the IOSB hall.*

# 4. When research meets people – our events

**Digital trade fairs and events**
The event celebrating our anniversary was to be the last large organized event for some time. Internal and external events, whether meetings, conferences or trade shows, were either canceled or, as was more often the case, moved to a digital format and reinvented as needed.

The Fraunhofer-Gesellschaft set up its own digital trade show "Solution Days" within a few months, at which Fraunhofer IOSB was represented with a number of solutions as digital exhibits as well as presentations. Research projects were started and finished in online conferences, and the functioning of developed technologies was captured on video rather than demonstrated live.

Hackathons got more attention than ever. In 2020, employees of Fraunhofer IOSB-INA participated in the #WirVSVirus major development competition organized by the German federal government, before founding the AICommunityOWL with other volunteers from partner organizations shortly after. This network of AI enthusiasts has already hosted two successful online hackathons around SmartFactoryOWL and the AI Living Lab, where participants were asked to solve challenges based on real industry data.

The learning curves for all involved were steep. In many cases, the virtual formats worked surprisingly well – but in some cases, especially for making new contacts, they unfortunately proved not to be a wholly adequate substitute for the usual event formats.

**Return to in-person events**
This made the few in-person events that had once more become possible by the time this report went to press all the more valuable. Of particular note is the IAA Mobility, which was held as an in-person event during the breather from the pandemic in late summer 2021. There, Fraunhofer IOSB presented the OCTANE simulation platform and its VERTEX test vehicles for experiments related to automated driving functions.

The Karlsruhe Research Factory was inaugurated with a ceremonial opening at the end of March 2022. Around 500 guests were curious to see the research projects and demonstrators on display in the three halls, including the State Premier, the Ministers of the Economy and Research of Baden-Württemberg, as well as numerous representatives of manufacturing companies. The following day, the first AI Systems Engineering Day for production took place in a somewhat smaller group in the IOSB hall of the Research Factory.

# Fraunhofer IOSB: A unique spectrum of scientific expertise

Developing new types of visual sensor systems; utilizing and connecting sensors in an optimal way; processing and evaluating the resulting data streams; helping people, on this basis, to make sound decisions; enhancing processes and controlling autonomous systems intelligently: this fully integrated process and value chain draws on the three core areas of competence enshrined in our name – the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB.

## Highest standards in everything we do

Our institute is Europe's largest research establishment in the field of image capture, processing and analysis. Our activities focus on a wide spectrum of areas, from the physical principles of signal generation to the algorithmic extraction of valuable information from sensor data. We also have wide-ranging expertise in systems engineering, which means we always have an eye for the full picture. In other words, we not only develop algorithms and individual components; we also build complete, ready-to-use systems that utilize sensor data to support people, automate processes and open doors to new forms of human-machine interaction. In everything we do, we implement the highest standards in terms of interoperability, IT security and data protection/privacy.

### The core competences

The institute's core areas of competence are spread among 16 scientific departments. According to their strategic and scientific orientation, our departments are constantly evolving. In 2021, the department "Water and Mobile Systems (WMS)" of the Advanced System Technology branch Fraunhofer IOSB-AST in Ilmenau was split into two new departments: "Underwater Robotics (UWR)" and "Embedded Intelligent Systems (EIS)". The new departments allow for a clearer focus on two research areas that have developed successfully in recent years.

In addition, a further research group links the institute with the university chair occupied by our head of institute. The competence triangle of expertise represented in the graphic to the right shows how individual departments are positioned in relation to the three core competences specified in the institute's name.

## Knowledge transfer with universities

The institute has locations with various research foci throughout Germany; longstanding sites include Karlsruhe, Ettlingen, Ilmenau, Lemgo, a branch lab in Görlitz and the Beijing liaison office. The Karlsruhe and Ettlingen sites cooperate closely with the Karlsruhe Institute of Technology (KIT): Head of institute Prof. Jürgen Beyerer heads the Vision and Fusion Laboratory at the Institute for Anthropomatics and Robotics (Department of Informatics). Prof. Marc Eichhorn, director of Fraunhofer IOSB Ettlingen, holds the Chair in Optronics at the Institute of Systems Optimization (Department of Electrical Engineering and Information Technology). The institute's other sites maintain similarly close ties to local universities, resulting in a Chair in Energy Usage Optimization at the Ilmenau University of Technology and various chairs at the universities of applied sciences of Schmalkalden, Zittau/Görlitz and Ostwestfalen-Lippe. Newer sites are the result of Fraunhofer-wide collaborations: The Smart Ocean Technologies (SOT) research group is based in Rostock, and in 2022, the Fraunhofer Center for the security of socio-technical systems SIRIOS was opened in Berlin.

## Core competences and structure

### Optronics

Understanding and control of the generation of light, its beam forming, propagation and conversion into electronic signals

- Laser Technology
- Optronics
- Signatorics
- Visual Inspection Systems

### System Technologies

Ability to analyze, understand, model, develop and control complex systems

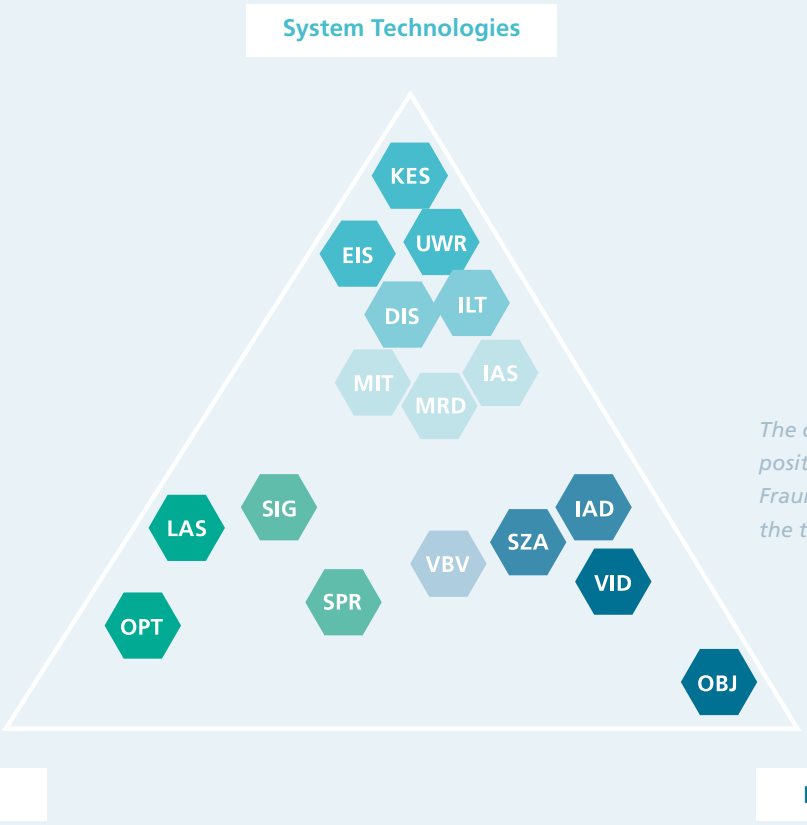
- Cognitive Energy Systems
- Digital Infrastructure
- Embedded Intelligent Systems
- Information Management and Production Control
- Interoperability and Assistance Systems
- Machine Intelligence
- Systems for Measurement, Control and Diagnosis
- Underwater Robotics

### Image Exploitation

Preparation and real-time processing of images and videos as well as automatic and interactive information extraction

- Interactive Analysis and Diagnosis
- Object Recognition
- Scene Analysis
- Video Exploitation Systems
- Variable Image Acquisition and Processing research group

## The competence triangle




*The competence triangle positions the departments of Fraunhofer IOSB in relation to the three core competences.*

# Expertise in applications and market-oriented solutions

**In order to ensure that our clients enjoy commercial success, we provide them with services, components and complete systems that are based upon a broad spectrum of technology, methodology and expertise. Creating best-of-class solutions demands not only first-class scientific and technical skills but also an in-depth knowledge of industry.**

## Three split funding allows successful research

As an institute committed to applications-oriented research, we source roughly one-third of our budget from projects for clients from a range of industries, including both private-sector companies and public-sector bodies such as municipalities or environmental and security agencies. A further one-third comes from publicly funded research projects, where we often cooperate with companies and other application partners as well as research organizations.

Such collaboration keeps us in continuous dialogue with a broad range of partners and helps us constantly deepen our applied know-how in the most diverse of domains. This, in turn, puts us in a prime position to pursue highly topical, game-changing scientific research and technological innovation, meaning that we are able to make optimal use of the final one-third of our financing, which is base funding.

## Serving specific market needs: Our business units

Our business units are the hubs where we concentrate our expertise in each of our various application domains. They provide solutions, services and products tailored to the needs of their specific markets. The departments referred to above define our organizational structure. By contrast, the business units form an additional layer that is superimposed on that structure and aligned with the various markets that we are addressing. The departments go through the individual business units to serve their specific markets.

**Business units**

- Artificial Intelligence and Autonomous Systems
- Automation and Digitalization
- Defense
- Energy, Environmental and Security Systems
- Inspection and Optronic Systems

Through our business units, we transport the results from our research to the user to tackle the challenges of the future. We focus on dialogue and cooperation both within our business units and in the business community beyond to maximize synergy.

## Selected strategic collaborations, expert networks and platforms we are participating in

CC-KING Competence Center KI-Engineering

ROBDEKON

Lernende Systeme – Die Plattform für Künstliche Intelligenz

PROFILREGION Mobilitätssysteme Karlsruhe

MorgenStadt City of the Future

Lemgo Digital

Industry IoT Consortium

International Data Spaces Association

GAIA-X data-infrastructure.eu

Karlsruher Forschungsfabrik

SmartFactoryOWL

it's owl

Plattform Industrie 4.0

Mittelstand-Digital

Allianz Industrie 4.0 Baden-Württemberg

Smart Electronic Factory

<AutomationML/> The Glue for Seamless Automation Engineering

KASTEL

Bauhaus.MobilityLab

Open District Hub Für die Zukunft der Energiewende

OGC Member

Innovationsallianz TechnologieRegion Karlsruhe

QAPPS Center for Applied Quantum Computing Saxony

Forschungsallianz Kulturerbe

# How to cooperate with us

**Our range of offerings and services covers a broad portfolio of competences and topics as well as the entire spectrum of development stages – from the basic research question to the finished product. In other words, you've come to the right place, no matter to which TRL (Technology Readiness Level) your question relates. For our customers from the economy and our sponsors from the public sector, we create, perform or develop:**

**Studies** You have a question – would you like to know, for example, what is technologically feasible in a certain area? We give you a neat written answer.

**Consulting** You would like to develop your company or project technologically? We support you with our know-how and facilitate concrete steps.

**Contract R&D** You have a technological problem or a previously unfulfillable requirement? We develop the solution.

**Demonstrators** You would like to illustrate the potentials of certain technologies using example applications? We find use cases and build functional exhibits.

**Prototypes** You need hardware or software that can cope with previously unsolved challenges? We do the engineering and deliver fully functional components and systems if required.

**Training courses** You would like to train yourself or your colleagues in specific topics that lie within our competence spectrum? We create trainings and events with a high practical relevance.

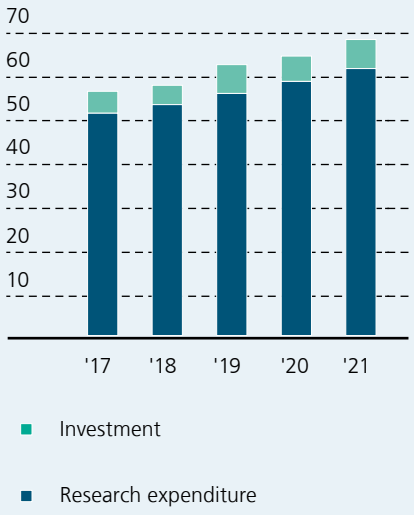
**Tailored to your needs**

If you are interested, please contact the relevant business unit or department. We look forward to talking to you and will be happy to make you an offer tailored to your specific needs.

# Key figures

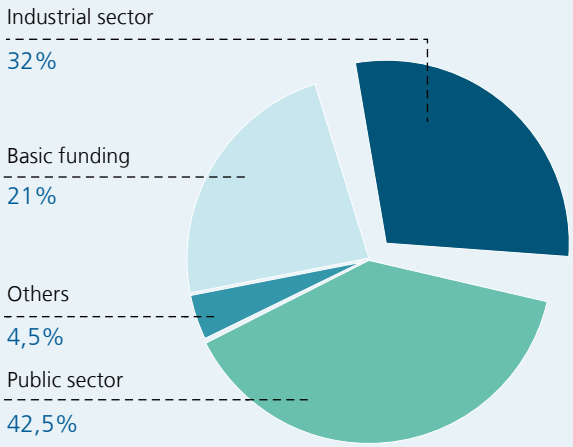
## Business expenses

How much money did we spend?



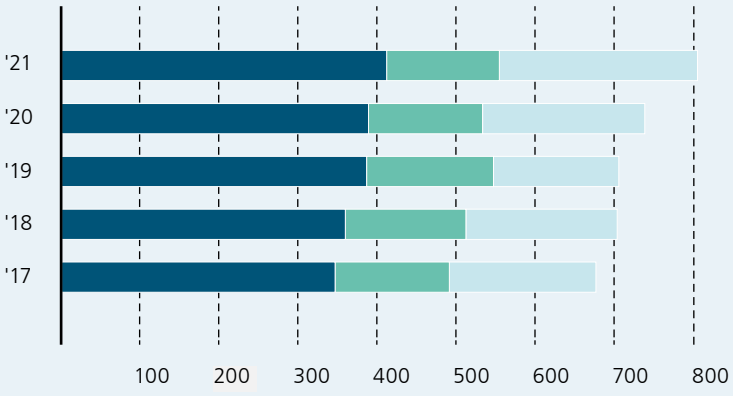

## Funding

Where did the money come from (in 2021)? *




## Staff

How many persons worked at Fraunhofer IOSB? **




* Preliminary figures as of March 2022

** Headcount reporting date: 31 December 2021

## Organization chart

### Head of institute

Prof. Dr.-Ing. habil. Jürgen Beyerer

### Board of directors

Prof. Dr.-Ing. habil. Jürgen Beyerer
Director Karlsruhe

Prof. Dr. rer. nat. habil. Marc Eichhorn
Director Ettlingen

### Deputies

Prof. Dr. rer. nat. habil. Marc Eichhorn

Dr.-Ing. Olaf Sauer

### Division manager Defense

Prof. Dr. rer. nat. habil. Marc Eichhorn

### Core competences

- **Optronics**
- **System Technologies**
- **Image Exploitation**

### Karlsruhe

**SPR | Visual Inspection Systems**
Prof. Dr.-Ing. Thomas Längle

**ILT | Information Management and Production Control**
Dr.-Ing. Thomas Usländer

**MRD | Systems for Measurement, Control and Diagnosis**
Dipl.-Ing. Christian Frey

**IAS | Interoperability and Assistance Systems**
Dr.-Ing. Rainer Schönbein

**IAD | Interactive Analysis and Diagnosis**
Dr. rer. nat. Elisabeth Peinsipp-Byma

**VID | Video Exploitation Systems**
Dr.-Ing. Markus Müller

**VBV | Variable Image Acquisition and Processing (research group)**
Dr.-Ing. Johannes Meyer

### Ettlingen

**OPT | Optronics**
Dr. rer. nat. Helge Bürsing

**SIG | Signatorics**
Dr. rer. nat. Karin Stein

**LAS | Laser Technology**
Dr. Christelle Kieleck

**OBJ | Object Recognition**
Dr. rer. nat. Michael Arens

**SZA | Scene Analysis**
Dr.-Ing. Karsten Schulz

## Ilmenau / Görlitz

**Advanced System Technology branch Fraunhofer IOSB-AST**

Prof. Dr.-Ing. Peter Bretschneider
Prof. Dr.-Ing. habil. Thomas Rauschenbach
Directors Ilmenau

### EIS | Embedded Intelligent Systems

Prof. Dr.-Ing. Andreas Wenzel

### KES | Cognitive Energy Systems

Prof. Dr.-Ing. Peter Bretschneider

### UWR | Underwater Robotics

Prof. Dr.-Ing. habil. Thomas Rauschenbach

## Lemgo

**Industrial Automation branch Fraunhofer IOSB-INA**

Prof. Dr.-Ing. Jürgen Jasperneite
Director Lemgo

### DIS | Digital Infrastructure

Dr.-Ing. Sebastian Schriegel

### MIT | Machine Intelligence

Dr. rer. nat. Oliver Niehörster

## Rostock

### SOT | Smart Ocean Technologies (research group)

Prof. Dr.-Ing. habil. Thomas Rauschenbach

## Berlin

### SIRIOS | Fraunhofer Center for the Security of Socio-Technical Systems

Dr.-Ing. Markus Müller

## Beijing

**Representative office China**

Dipl.-Ing. Hong Mu

## Administration

**Head of administration / Commercial and Technical Management**
Dipl.-Betriebsw. (FH)
Nicole Keller-Rau

**IT security**
Dipl.-Inform.
Birger Krägelin

## Staff department

**Head of Staff department and Strategy and Innovation Management**
Dr. rer. nat.
Frank Lorenz

**Press and Communications**
Dipl.-Phys.
Ulrich Pontes

# Pooling expertise

**The institutes of the Fraunhofer-Gesellschaft cooperate with each other in different constellations, leveraging synergies and securing Fraunhofer's leading position in the development of system solutions and the implementation of holistic innovations. The "Powerhouse" depicted on the right shows the organizational and funding structure of the Fraunhofer-Gesellschaft. The aim is to enable consistent and interlinked scientific value creation – from outstanding upstream research to successful technology transfer.**

## Impact goals

Under the Powerhouse roof, five **impact goals** define key societal challenges to which the Fraunhofer-Gesellschaft is committed.

Fraunhofer IOSB makes important contributions to four of them: *Energiewende* (energy transition) accomplished, digitalized value chain, fully circular economy, and a secure and resilient society.

## Fraunhofer Strategic Research Fields

The seven **Strategic Research Fields** aim to address needs and markets that will shape our future. Within these fields, outstanding pre-competitive research specifically targets projects that have high commercial potential, thereby enhancing our impact on society and across multiple sectors. The content and strategic design of the SFFs is supported by lighthouse projects and clusters of excellence.

Through its involvement in two expertise-oriented groups, two Clusters of Excellence, eight Fraunhofer Lighthouse Projects and seven Fraunhofer Alliances, Fraunhofer IOSB is active in all Fraunhofer Strategic Research Fields. In addition, our institute director Prof. Jürgen Beyerer is the spokesperson for the Fraunhofer Strategic Research Field Artificial Intelligence (see p. 27).

## Expertise-oriented groups

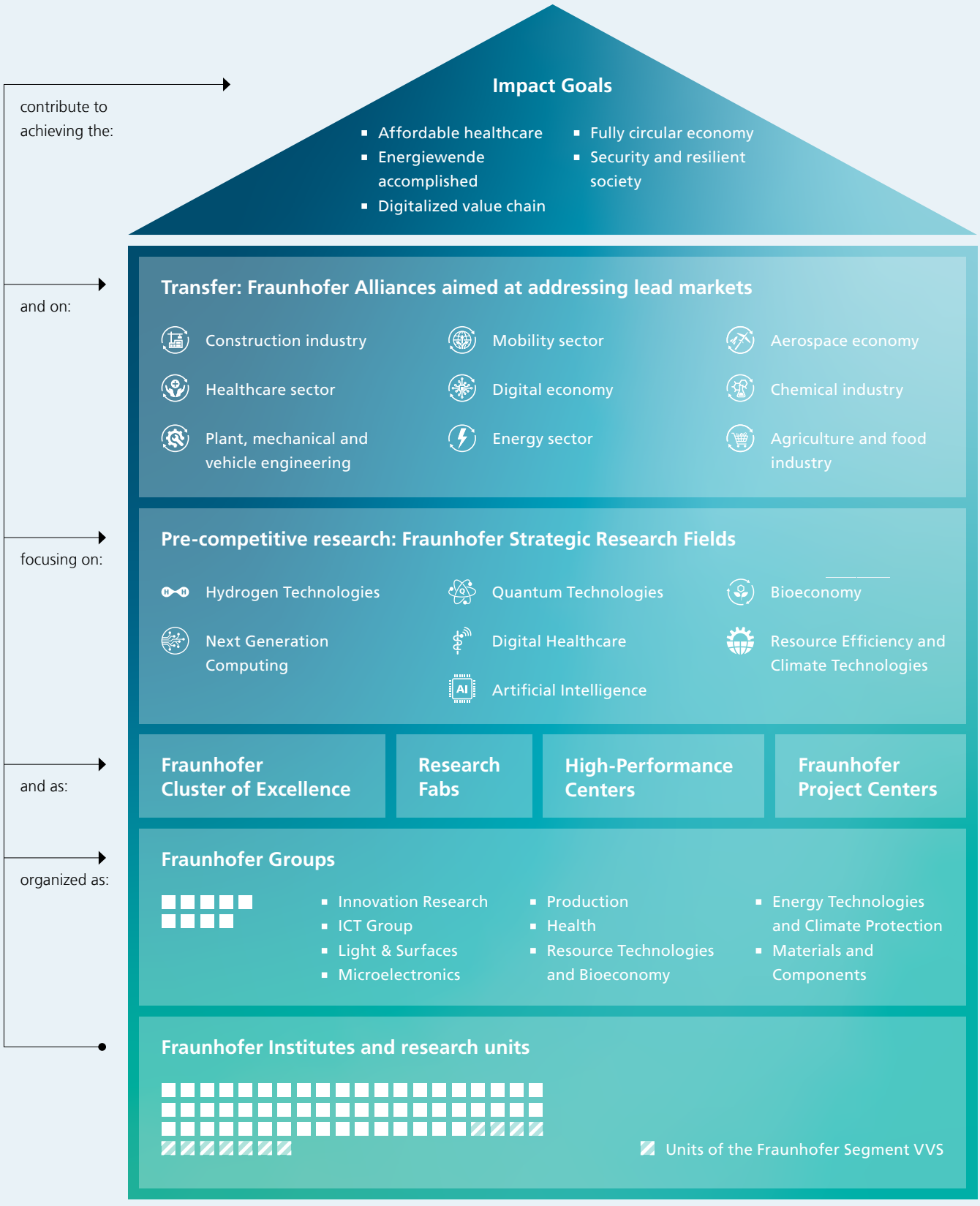
Institutes working in related subject areas cooperate in **expertise-oriented groups** and foster a joint presence on the R&D market. The mission is to secure and further develop scientific excellence in the respective field of excellence, through shared resources and leveraged synergies. The groups' chairpersons are part of the Presidential Council of the Fraunhofer-Gesellschaft.

Fraunhofer IOSB is a member of the **Fraunhofer ICT Group:** the largest provider of applied research in the field of information and communication technologies in Europe. It marshals key expertise for business and society to utilize in exploiting opportunities and meeting the challenges that result from the comprehensive digitalization of virtually all aspects of today's new world. It covers a broad spectrum of technological fields through its member institutes, from the basics to practical solutions, and offers assistance to national and international IT providers and IT users alike, particularly SMEs. In addition, it defines and works on the predominant topics crucial for the future of business and society through interdisciplinary initiatives at the highest conceptual level. Technology fields: numerical software & simulation, usability & human-computer interaction, reliable cyber physical systems, IT security & safety, digital networks & the Internet, computer graphics & media technology, image acquisition & evaluation, big data management & analytics, automation technology & engineering.

Moreover, Fraunhofer IOSB is guest member of the **Fraunhofer Group for Light & Surfaces,** which focuses on lasers, optics, metrology and coating technology, and of the Fraunhofer **Group for Energy Technologies and Climate Protection.**

Due to the broad spectrum of expertise it represents, the Fraunhofer Group for Defense and Security VVS was reorganized into the **Fraunhofer Segment for Defense and Security VVS** (see p. 28). Nonetheless, it is still headed by Fraunhofer IOSB.

## Fraunhofer structure



## Lead markets and lead-market oriented alliances

The **lead-market oriented alliances** facilitate customer access to the services and research results of the Fraunhofer-Gesellschaft. Points of contact for groups of institutes active in related fields provide expert advice on complex issues and coordinate the development of appropriate solutions. They address sectors that are highly relevant to Germany and Europe's innovative strength – referred to as **Fraunhofer lead markets**. In these lead markets, innovations give Germany a global competitive advantage, secure Germany and Europe's technological sovereignty and generate sustainable value for society.

Fraunhofer IOSB and individual departments are members of the following Fraunhofer alliances (and seven out of eight lead markets):

- Automobile Production (Plant, mechanical and vehicle engineering)
- Big Data and Artificial Intelligence (Digital economy)
- Energy (Energy sector)
- Food Chain Management (Agriculture and food industry)
- Space (Aerospace economy)
- Traffic and Transportation (Mobility sector)
- Water Systems (Energy sector)

Furthermore, the institute is part of the Business Unit Vision: an association of specialist departments from several Fraunhofer Institutes that work together and pool their expertise in the fields of industrial image processing, machine vision and optical measurement and testing technology.

## Lighthouse projects

In its **lighthouse projects**, Fraunhofer is tackling the current challenges facing industry head on. These 3- to 4-year projects with budgets of several million euros focus on topics geared towards strategic economic requirements, with a view to turning original scientific ideas into marketable products as quickly as possible.

Fraunhofer IOSB participates in eight out of 16 ongoing or recently completed lighthouse projects:

- ML4P: Machine Learning for Production (this project is coordinated by Fraunhofer IOSB)
- COGNAC: Cognitive Agriculture
- MED²ICIN: Digital patient model as a basis for personalized and cost-optimized treatment
- QUILT: Quantum Methods for Advanced Imaging Solutions
- ALBACOPTER®: Experimental Vertical Take-Off and Landing Glider
- SWAP: Hierarchical swarms as production architecture with optimized utilization
- Waste4Future: From waste to raw material – green molecules for chemistry
- FutureProteins: Coupled agricultural systems for the resilient and sustainable production of high-quality food proteins

## Clusters of Excellence

Acting as a "virtual institute" spread over multiple locations, the **Clusters of Excellence** promote cooperative development of system-relevant topics through an inter-institute research structure. Their purpose is to follow a roadmap for the long-term development of complex technological trends.

Fraunhofer IOSB participates in the cluster **Cognitive Internet Technologies,** which explores cognitive technologies for the industrial Internet and develops key technologies along the value-added chain – from sensors to intelligent learning processes in data processing to the cloud. The research cluster **Integrated Energy Systems** addresses the central technical and economic challenges of the next phase of the global energy transition, pursuing the vision of transforming Fraunhofer into the lead research institution for applied energy research.

## High-Perfomance Centers

**High-Performance Centers** organize strategic topic-based collaboration between universities, higher education institutions, Fraunhofer-Institutes and further non-university research institutions, creating a locally anchored ecosystem to improve the economic impact and societal benefits of R&D. They bring together appropriate partners and guide ideas to market launch, through cross-organizational use of infrastructure, education concepts and know-how.

In the High-Performance Center **"Mobility Systems, Karlsruhe,"** Fraunhofer IOSB and its partners are investigating the mobility of the future.

Fraunhofer IOSB-AST is part of the High-Performance Center **"Intelligent Signal Analysis and Assistance Systems – InSignA, Ilmenau"** (see p. 64).

The High-Performance Center **"Sustainable Ocean Business" in Rostock** focuses on solutions for underwater technologies and brings together the Fraunhofer institutes in the Smart Ocean Technologies (SOT) research group with other local partners.

# Fraunhofer Strategic Research Field Artificial Intelligence

In the factory, office and everyday life, artificial intelligence systems are taking on ever more routine tasks. Technologies like machine learning are transforming entire industries and are playing a key role in the future transformation of our society and economy. Independent and comprehensive AI expertise is important so as to avoid becoming dependent on players with possibly lower requirements in terms of data protection or security, for example, and to guarantee Germany's and Europe's competitiveness in these strategically and economically crucial technologies.

## AI technology you can trust

The Fraunhofer Strategic Research Field Artificial Intelligence (FSF AI) explores key technologies for AI-based services and products. With our comprehensive methodical and application competence, we are developing trustworthy, secure and sustainable AI technologies to help our customers solve their practical problems.

Fundamental questions, such as the explainability of AI methods, the systematic engineering of AI-based systems or the integration of expert knowledge into machine learning methods, are focal points of our developments. The FSF AI aims to take AI technologies from concept to application; our solutions will be applied in many different fields – from autonomous driving to intelligent production plants and medical engineering.

## At present, the Strategic Research field AI is focusing on seven future-oriented topics:

- **AI Systems Engineering**
  - Systematic engineering of AI
  - Specification, planning, dimensioning of AI
  - Energy optimized AI
- **Embodied AI**
  - Robots and autonomous systems
  - Edge and IoT systems
  - Hardware/software co-design
- **Hybrid AI**
  - Combining data-driven learning with knowledge and models
  - Small/relevant data
  - Development/optimization of algorithms
- **AI and the Human**
  - Speech and dialog systems
  - Intelligent agents, collaborative systems
- **Certified AI**
  - Explainability, traceability
  - AI safeguarding (safety/security), attack and defense
  - Standardization
  - Human control of AI
- **AI and Hardware**
  - Hardware/software co-design, neuromorphic computing
  - Quantum AI and corresponding algorithms

Data and sustainability underpin each of the focus topics. The sustainable use of computing resources and data over their entire life cycle (data value chain) plays an equally important role as data quality and data sovereignty.

**Fraunhofer Strategic Research Field Artificial Intelligence**

**Spokesmen**
Prof. Dr.-Ing. habil. Jürgen Beyerer, Fraunhofer IOSB
Prof. Dr. Stefan Wrobel, Fraunhofer IAIS

**Deputy spokesman**
Prof. Dr. habil. Alexander Martin, Fraunhofer IIS

# Fraunhofer Segment for Defense and Security VVS

## We carry out research into the security of mankind, society and the state – for a life of freedom

**In times of social and political unrest, defense and security become ever more vital. We develop technologies, products and services designed to detect dangerous situations at an early stage, counteract them and minimize any harmful consequences, thus reducing risk overall.**

The Fraunhofer Segment for Defense and Security pursues research and development in the areas of defense and civil security. Our wide-ranging expertise and research have delivered highly practicable solutions and operational support, both at the national and international level. Our technical solutions and systems in civil security are designed to deliver the best possible protection for society. In defense technology, our competence in analysis and evaluation makes us indispensable independent experts and partners to the German Ministry of Defence (BMVg). We research and develop technologies and system solutions for the ministry, the government bodies within it and for the German armed forces. Pooling the interests and activities of our member institutes, we act as their representative both within and outside the organization. By facilitating mutual support, sharing competences, dividing tasks and coordinating the areas in which we specialize, we generate benefits for the entire segment.

### Resilience through research

The Fraunhofer Segment for Defense and Security delivers comprehensive security models, with research focusing on protection against military, technological, terrorist, natural and criminal threats. Our research targets the following areas:

- Systems and technologies for use on land, in the air, in the water, in space and in cyberspace
- Gathering information, and providing information and decision-making support
- Networked operations
- Protection and impact
- Electronic warfare
- Cross-system technologies
- Resilience and protection of critical infrastructures
- Combating terrorism and crime
- Border security
- Crisis and disaster management
- Digital transformation

### Our core capabilities

- Coordinating large-scale projects
- Delivering system solutions for complex issues

### Our unique features

- Excellent infrastructure and laboratory equipment
- Technical expertise always available
- Superb network with research, industry and government
- Well-founded assessment and consulting skills in defense research and technology
- Interdisciplinary work and broad technology portfolio

### Range of services

- Feasibility studies
- Strategic foresight, scenarios and roadmapping
- Analyzing technological needs and trends
- Developing methods, technologies, components and systems
- Assessing systems, including those of third parties
- Developing prototypes and processes
- Pilot series production

### Members and associated members

- Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI
  **Protection, Security and Effects**

*ASSTA 3.1-Tornado.*

- Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR
  **Radar – A Key Technology**
- Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE
  **Command, Control and Reconnaissance**
- Fraunhofer Institute for Applied Solid State Physics IAF
  **Sensors for Safety, Security and Reconnaissance**
- Fraunhofer Institute for Chemical Technology ICT
  **Security, Safety and Energetic Materials Technology**
- Fraunhofer Institute for Technological Trend Analysis INT
  **Planning Support for State and Industry**
- Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB
  **From Networked Sensor Data to Decision**
- Fraunhofer Institute for Experimental Software Engineering IESE
  **Software and Systems Engineering**
- Fraunhofer Institute for Integrated Circuits IIS
  **Communication, Positioning Technologies and X-Ray for Safety and Security Applications**
- Fraunhofer Institute for Structural Durability and Systems Reliability LBF
  **Secure Processes for secure Structures**

**Fraunhofer Segment for Defense and Security VVS**

**vvs.fraunhofer.de**

**Chairman**
Prof. Dr.-Ing. habil. Jürgen Beyerer,
Fraunhofer IOSB

**Deputy chairman**
Univ.-Prof. Dr.-Ing. Dr. rer. pol. habil.
Michael Lauster
Fraunhofer IN

**Deputy chairman**
Prof. Dr. rer. nat Peter Martini,
Fraunhofer FKIE

**Managing director**
Dipl.-Ing. Caroline Schweitzer,
Fraunhofer IOSB
caroline.schweitzer@iosb.fraunhofer.de

# Business Units

**Our business units are the hubs where we concentrate our expertise according to application domains. They provide solutions, services and products tailored to the needs of their specific markets.**

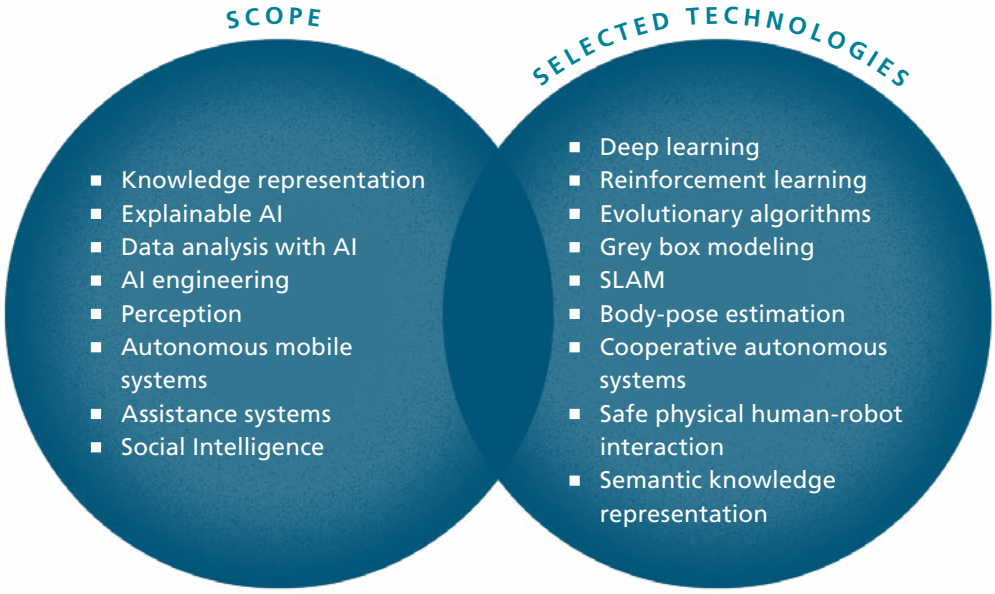
# Artificial Intelligence and Autonomous Systems

## From basic questions to embodied AI

The business unit Artificial Intelligence and Autonomous Systems conducts applied research throughout the entire field of artificial intelligence and machine learning. We provide our partners and customers with a wide range of methodological and applied expertise not only in the much discussed field of deep neural learning but also in many other areas besides.

We focus on basic questions such as algorithmic transparency, the integration of expert knowledge, and AI engineering. At the same time, we also develop solutions for concrete applications. These include environmental sensing, diagnostic and adaptive learning systems as well as solutions for localization and motion planning, behavioral analysis, data analysis and reasoning, anomaly detection, decision support and knowledge representation. A further area of research is embodied AI. This is what enables us to endow excavators and drones with intelligent autonomy, create solutions for autonomous vehicles, and build assistance systems for the manufacturing and medical sectors.

Artificial Intelligence and Autonomous Systems was established at the beginning of 2019 with a view to amalgamating our wide-ranging expertise in AI and delivering new advances in this field. When it comes to developing AI-based applications in areas such as manufacturing, inspection, energy and security, we work in close cooperation with other business units.




**Contact**

Spokesperson
Dipl.-Ing. Christian Frey
Phone +49 721 6091-332

Deputy spokesperson
Prof. Dr.-Ing. Andreas Wenzel
Phone +49 3677 461-144

**iosb.fraunhofer.de/ki**

**Departments involved**

- DIS
- EIS
- IAD
- IAS
- ILT
- MRD
- KES
- VID
- UWR


# Our XAI tools shed light on the black box«

Explainable Artificial Intelligence (XAI): important tool for AI systems engineering and the predictable, systematized use of AI in demanding applications

**Mr. Frey, why is the concept of explainability such a big issue when it comes to AI methods?**
Although AI algorithms such as deep learning methods often deliver impressively good results, it is usually hard to understand how and why these algorithms produce certain results. XAI aims to fill this gap. XAI stands for a group of methods that in a sense shed light on the black box and are designed to make it easier to interpret the decisions of AI models. This is not only important for the issue of acceptance – in other words, that humans trust and accept the decisions made by an AI. It is also an important tool for the development phase and the subsequent life cycle of AI components in the context of AI systems engineering, for example to track down the causes of errors.

**Do you have any concrete examples?**
We use a variety of methods, depending on whether explanations are required only for a specific case or in general, how much is known about the underlying AI model, etc. Semantic XAI, for example, is based on knowledge models and can generate textual reasoning along the lines of: "This object is very probably a car because I have detected two wheels, headlights, exterior mirrors and a license plate in the image." Or, in the case of AI-assisted route planning for autonomous systems, XAI methods visualize the decisions that lead a robot system on the best path through unknown terrain in a way that humans can clearly understand.

**What specific range of services does the IOSB offer in this area?**
In the context of an internal research and development program, we have focused on building up targeted XAI expertise for more than two years. This expertise is embedded in our comprehensive and applied AI knowledge in sectors ranging from industrial production, automotive and medicine to energy. One of the results is an XAI toolbox that is available immediately for analyzing data, debugging and explaining the predictions of any black-box model. This means that we can support virtually any type of AI application project and contribute significantly to developing not just "pretty" proof-of-principle demonstrators, but robust, practical and accepted productive solutions.

**Dipl.-Ing. Christian Frey**

Business unit spokesperson
Head of MRD department
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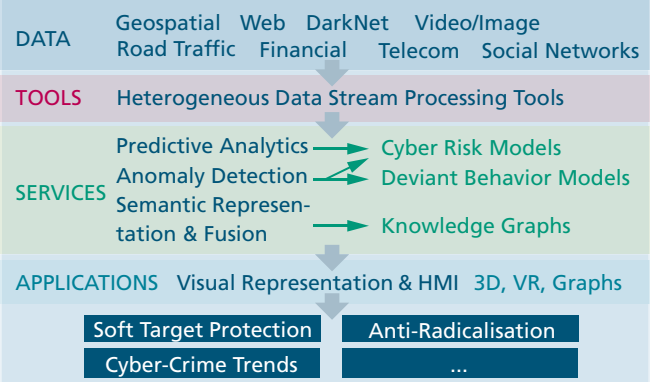


*PREVISION platform architecture.*

*3D model of an above-water structure.*

## Prediction and Visual Intelligence for Security Information (PREVISION)

PREVISION's objective was to support law enforcement agencies (LEAs) in the analysis of large, heterogeneous data sets using modern artificial intelligence methods, and thus contribute to the prevention and investigation of crime and terrorism. The project, completed in 2021, was funded by the EU and involved 28 partners.

Based on an iterative development methodology, frequent software releases were made available to end-users for testing and evaluation. The PREVISION platform was deployed in 10 different demonstrations managed by the different LEAs and practitioners of the consortium. Based on selected deployment scenarios from the application areas of counterterrorism, white-collar crime and art smuggling, the project first identified the need for solutions, specified technical requirements, concretized ethical and legal guidelines and discussed the impact of crime and crime-fighting methods on society.

Based on this, established algorithms of text, image and audio processing have been tailored to the respective use cases and existing AI methods have been further developed. A core objective was the semantic merging of manually and machine-derived facts in an ontology-based knowledge model. By using methods of data classification, machine reasoning and data clustering, information hidden in the data stock can be revealed and temporal trends for the development of threads can be derived. The functionality has been realized in a modular, future-proof architecture with open interfaces, favoring the emergence of a new market for surveillance technologies.

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## Semi-autonomous survey system for rivers and lakes

The precise surveying of bodies of water such as rivers or quarry lakes is a demanding task, and until now a manual and highly time-consuming one. As part of a three-year in-house research project, Fraunhofer IOSB has developed an autonomous surface vehicle that can measure a body of water autonomously in order to produce a 3D map of it. To achieve this, it uses sonar to measure the bed of the body of water, and optical systems to measure the bank or shore and above-water structures. The information obtained in this way is then merged and incorporated into a combined 3D model of the environment.

The surface vehicle is equipped with a number of additional sensors for autonomous driving, such as acceleration and rate-of-turn sensors or GPS. A laser scanner is used for bank and shore mapping and also for avoiding obstacles during the measurement run, allowing the vehicle to circumvent other ships or buoys and avoid collisions. The measurement vehicle is steered by the "Algorithm Toolbox for Autonomous Mobile Robot Systems," developed at Fraunhofer IOSB, connected via a radio channel to a "digital map table." This is the human interface that allows the survey mission to be specified and the results to be visualized.

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*The project is creating a cloud platform for various AI applications in urban environments.*

*Mock-up system with same kinematics as the project's battery-powered electric target systems captures data on airport apron.*

## Bauhaus.MobilityLab in Erfurt – the living lab of the future

The "Bauhaus.MobilityLab" project is using Erfurt's Brühl district as a living lab to develop and test a range of AI-based applications: Traffic lights will be controlled according to traffic volume, deliveries will be made in a more customer-oriented manner, local energy generation will reduce electricity costs and intelligent tariff systems will determine the charge price for electric cars. The applications will be developed and provided on a cloud platform that collates data from different areas, such as transport, logistics and energy.

Under the consortium leadership of Fraunhofer IOSB-AST, the "BML Ecosys" platform forms the basis for the overarching development and testing of AI-based mobility, logistics and energy services in a real-world urban environment. The lab platform will be run by an operating company with the involvement of all project partners. The concept of the Bauhaus.MobilityLab will act as a blueprint in terms of a "lab as a service" for the development of future urban living labs and even for other fields of application. German and international cities have already expressed their interest in the project.

## Energy management and automation of battery-powered special-purpose vehicles

At the core of the ALEC project funded by the Federal Ministry for Economic Affairs and Climate Action is the development of battery-powered electric vehicles for the airport apron. The main focus is on equipment carriers with tool changing systems. One aim is to develop an energy management system for the airport and a charging management system for the vehicles that makes use of their flexibility combined with local photovoltaics to save $CO_2$. This is the basis for a concept for the future supply of energy to the airport.

Another focus is automatic driving, which increases the reliability and efficiency of vehicle use. To this purpose, a specially adapted sensor concept is being developed to identify the enviroment of the vehicles on the airport apron, ensuring stable localization and the reliable detection of obstacles.

The prototypes for energy and charging management have been successfully implemented and tested in simulations using realistic input data, allowing $CO_2$-optimized battery charging to be demonstrated and future potential for development to be identified. The future energy concept for the airport has also been created. As well as the sensor and navigation concept for autonomous driving that has been developed, a specially built mock-up system has been used in the project to record sensor data at the airport and develop simulations based on it. These simulations allow to adjust the transport processes on the airport apron to evaluate the localization, path planning and path adjustment algorithms developed for autonomous driving in different situations and with different vehicle kinematics.

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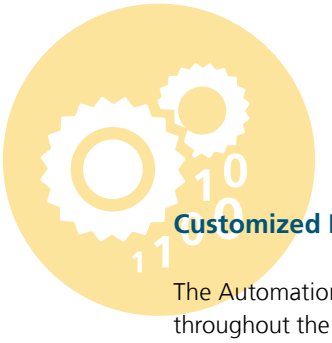
# Automation and Digitalization

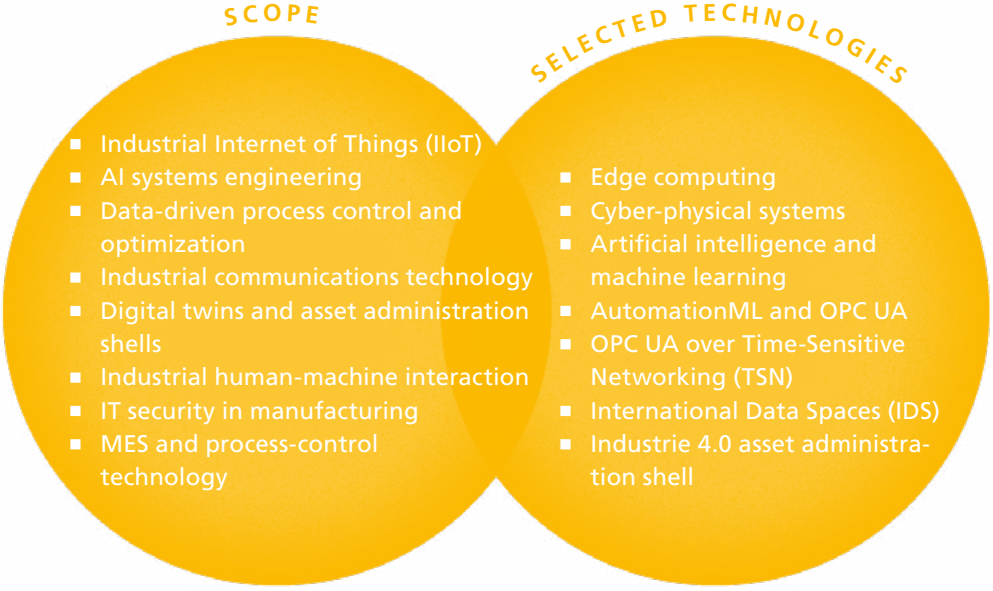


## Customized IT for networked production ecosystems

The Automation and Digitalization business unit provides a highly focused range of services throughout the entire automation pyramid within and between industrial production plants. This includes solutions for manufacturing companies, system integrators, machine suppliers, automation providers and software vendors delivering production-related IT including the supplier network.

We focus on creating innovative, customized and functional IT solutions for complex manufacturing processes and networked production ecosystems. For many years, we have been designing, developing and delivering pioneering system solutions for industrial applications, ranging from measurement and control technology to embedded systems and sophisticated production-control and MES systems. Our activities are concentrated in the following fields: Industrie 4.0, IT security in the industrial Internet of Things (IIoT), collaborative human-machine systems, digital twin systems, and customized AI methods (esp. machine learning) for use in manufacturing, assembly and supply chains.

Our ambition is to provide secure and service-oriented architectures, AI systems engineering and information management based on open standards. With the SmartFactory OWL and the Karlsruher Forschungsfabrik (Karlsruhe Research Factory), we offer cutting edge development and demonstration environments for SMEs and for major corporations.

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# The AIoT trend is heralding new possibilities«

Artificial Intelligence of Things: How combining networked sensors and actuators with artificial intelligence is raising new research questions and creating new business modelssystematized use of AI in demanding applications

**Dr. Usländer, what does Artificial Intelligence of Things – AIoT for short – refer to?**
Thomas Usländer: AIoT is all about merging Internet of Things technologies with methods and tools used in artificial intelligence. This interplay creates huge added value in every IoT domain, especially automation technology and networked industrial production. That's because the "things" in the IoT, such as machine tools, can use sensors to supply exactly the data that machine learning (ML) methods need and that can be quickly evaluated and efficiently converted into useful information by these very methods. This opens up the scope for new applications and business models – and it raises exciting research questions.

**Could you give us some examples?**
A fascinating area of research is federated learning, in which an ML model is trained on multiple devices. Instead of exchanging all data, parts of the ML model are generated locally and then combined to form one large model – an approach that has particular advantages for data protection. An exciting concrete innovation topic is the application of ML methods in digital twins of production facilities and their assets, whereby the digital twins are continually synchronized with the states and behavior of the real "things".

**How can companies exploit this potential?**
Many companies have already invested in digitalizing production processes and the accompanying IoT technologies: for example, to monitor their facilities remotely. The logical next step is to evaluate data using AI solutions that can be implemented in the edge or in the cloud. However, this does mean bringing together a range of areas and disciplines – specifically, production engineering, informatics/IT and data science/AI. As we know from many projects in practice, this is by no means trivial: The use of AI methods is hard to plan and subject to its own laws, which are often alien to engineers and can be difficult to reconcile with the operational culture of established production facilities. However, we have the expertise and the AI systems engineering methods and tools that are needed to provide companies with the best possible support during this transformation journey.

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*Flexible, digitized production at Mercedes-Benz: In the TecLines, classic assembly lines are replaced by automated vehicles.*

## SWAP – Heterogeneous, workload-optimized robot teams

In the SWAP lighthouse project, ten Fraunhofer institutes are developing technological concepts for the future of modular and self-organized production. In order to respond to rapid product generation changes, customization requests or unpredictable sales fluctuations, modern production systems need to be easily expandable and versatile. At the same time, the effort required to adapt them on the planning and control system side needs to be minimized.

SWAP is creating the basis for a production environment where control is no longer centralized, but decentralized into hierarchical swarms with participants that work together collaboratively and (partly) autonomously. To achieve this, the interaction between the equipment and process control needs to be independent of the manufacturer.

As part of the project, we are designing and developing the architecture to map and control the equipment. At its core, the communication relies on a flexible OPC UA-based data hub. Coordination is carried out by an "execution engine" which can be seen as a generic process control system. This allows equipment to be reconfigured flexibly or replaced without the need for time-consuming process control adaptations.

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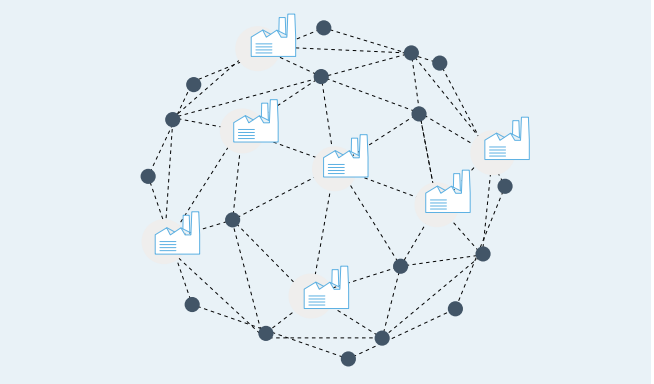

*A platform that mediates networked production capabilities and shares resources based on open standards and data sovereignty.*

## Smart Factory Web – blueprint architecture for federated industrial marketplaces

The Smart Factory Web (SFW) implements a reference architecture for open marketplaces to be used for networked stakeholders in industrial production ecosystems. It applies the principles of the platform economy to industrial production including the associated supply networks. Commercial offers of "production as a service" typically lead to proprietary systems with the risk of platform vendor lock-ins. Conversely, SFW follows an open approach and the principles of data sovereignty.

The SFW originated from a testbed of the Industry IoT Consortium (IIC) in 2015 together with the Korean research organization KETI. Later on Microsoft and SAP joined to leverage business cases. Meanwhile, the SFW has turned into a blueprint architecture for flexible shop-floor capacity and supply chain management based upon data sharing platforms such as GAIA-X and Catena-X.

The SFW allows factories to offer production capabilities and share resources to improve order fulfillment in a much more flexible way so that resilience and transparency requirements for supply networks may be fulfilled. The Fraunhofer Advanced Asset Administration Shell Toolkit (FA³ST) provides a powerful framework to realize SFW services. It integrates Industrie 4.0 and International Data Spaces (IDS) concepts with international standards such as OPC UA and AutomationML.

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*Built from real-world components, our demonstrators enable cyberattacks and countermeasures to be tested realistically.*

## Cybersecurity training labs

We operate two cybersecurity training labs, both of which have been among Fraunhofer Academy's "outstanding learning sites" since February 2021.

Our cybersecurity training lab for energy and water supply in Ilmenau and Görlitz sensitizes participants to the increased vulnerability of digitized energy and water infrastructures to cyberattacks. The threats are addressed in the 2021 white paper, "Current Cybersecurity Challenges in Energy Supply." Realistic replication of power and water systems is guaranteed by real telecontrol, protection and control system components as well as real-time simulations.

Our cybersecurity training lab for industrial manufacturing, based in Karlsruhe and Lemgo, combines learning modules with a tailored education environment. It features experimental hard- and software systems that are built from real-world automation components. Like the cybersecurity training lab for energy and water supply, it lets users see the consequences of cyberattacks and apply and test countermeasures. Since October 2021, we have been managing a "Cybersecurity Fundamentals" training program for VDMA (mechanical engineering industry association) members. The program is a cooperation between the International Society of Automation (ISA) and Maschinenbau Institut GmbH (MBI), a service company of VDMA.


*CC-KING is funded by the Baden-Württemberg Ministry of Economic Affairs, Labor and Tourism.*

## Making AI manageable for engineers

CC-KING, the Competence Center Karlsruhe for AI Systems Engineering, develops methods for engineers to apply artificial intelligence (AI) and machine learning (ML) in practice in a predictable and secure way. In AI systems engineering, CC-KING is combining cutting-edge AI research with established engineering disciplines to investigate methods and tools that directly benefit the economy, and small and medium-sized enterprises in particular.

As a leading partner in the consortium, we are contributing our extensive IT expertise in industrial automation and control systems as well as in the fields of AI and ML. Our partners in the consortium are FZI Research Center for Information Technology and Karlsruhe Institute of Technology (KIT). Practical relevance is ensured through transfer measures such as training in the CC-KING training lab, low-threshold advisory services (quick/transfer checks) and close collaboration with businesses in the CC-KING innovation committee.

In order to support businesses with the successful execution of AI projects in demanding areas such as mobility or industrial production, the first systematic Process Model for AI Systems Engineering was published as a white paper in late 2021. PAISE® describes and guides through the entire process from the design of AI-based technical systems to data acquisition, operation and maintenance, and supporting the development of AI-based sub-systems in an agile manner.

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# Defense

**Expertise in analysis and evaluation, contract research and technological innovation – from the physics of signal generation to the use of the information contained therein**

The Defense business unit conducts research in the following fields: imaging with optronic systems, real-time image and signal analysis, and architectures for information and simulation systems. We provide the German Federal Ministry of Defence, its subordinate offices and agencies, and the defense industry as a whole with expertise in analysis and evaluation of defense-related projects as well as concrete technology projects and contract research and development. Our prime objective is to ensure rapid transfer of the latest research so as to enhance the capabilities of the German armed forces and protect soldiers.

In order to realize the greatest possible synergies, our work is embedded, wherever possible, within the research for civil security and other applications that is performed at our other business units. We also maintain strong ties to various bodies, institutions and organizations within the EU, NATO and the scientific community.

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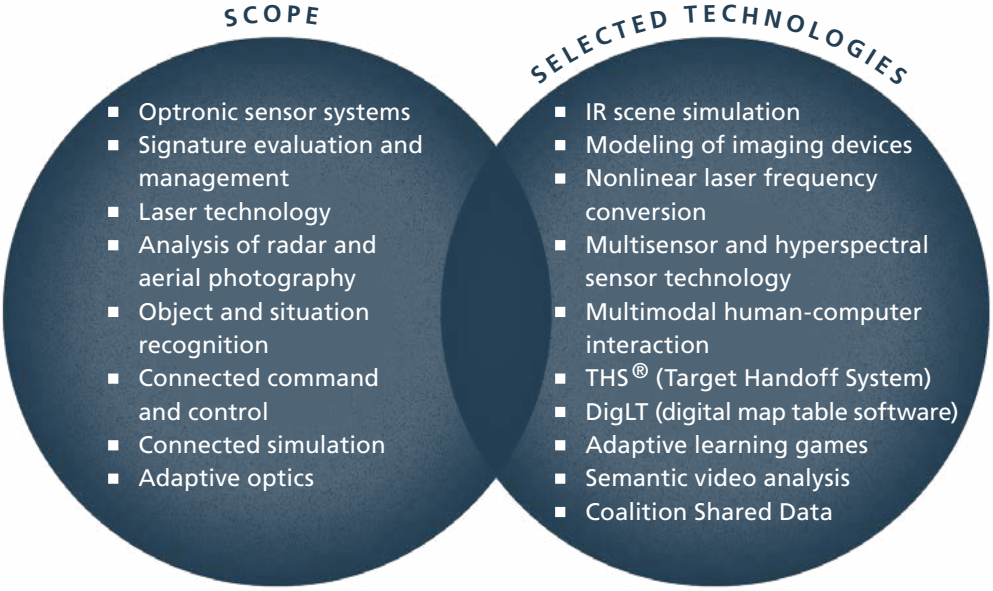

# We are making deep learning more robust«

The specific challenges of data-driven processes: How the right tools can help to supply sufficient training data and avoid misclassifications

**Dr. Arens, AI processes, for instance those used to classify images, are very efficient. In spite of this, they are only hesitantly making their way into practical applications. Why is this?**
Michael Arens: Despite their renowned performance, deep learning processes also continuously attract attention when they make serious mistakes: AI processes are often overwhelmed by specifically selected input data. This is why a key issue for us is robustness: How can we make sure that AI will deliver the desired outcome for any situation and that it will not, for example, think that a picture of a butterfly is actually a plane because of a certain cloud texture in the background? Something like this could happen as a result of a paradigm change borne by machine learning: Rather than on algorithms, results depend on training data. When the AI system is learning, millions of parameters are set based on the training data, resulting in a type of black box that will determine – in complex and barely comprehensible ways – which outputs are caused by specific inputs at a later date.

**So, can the key to robustness be found in the training data?**
Exactly. The training data must describe the problem comprehensively. Ideally, they cover the whole range of what might be input at a later date. There are, however, other aspects which play a defining part in our work. Such as: Can we find weak spots and use them to outwit the AI, for example to avoid detection? We are covering this in a project on camouflage and camouflage assessment (see next page). Or, another important aspect, what will happen when the input data systematically shift because the sensor gets old, for example – will the process still be robust? To address this kind of question and systematically make the process more resilient, we are also investigating various tools that allow for a look into the black box.

**What approaches could ensure that there is sufficient training data?**
In our field of business, a general lack of training data poses a challenge. This data doesn't accumulate on a daily basis to the same degree that it does for most other fields of application. This is especially the case for multispectral data, which plays an important role in defense research. Data produced by simulations may help. So may artificial variations of real data. A third approach is to transform existing data. In such a way, infrared data can be generated from conventional images acquired in the visible spectrum, though an appropriate AI process is required for this. We are exploring and developing tools for all of these approaches.

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## Camouflage assessment: How to deceive neural networks

Artificial intelligence has become an indispensable part of many applications, with its main advantage being that it is very fast at classifying objects in images, can be obtained pre-trained or be trained on object classes of interest, and can therefore quickly search very large data sets, like video feeds, for objects or even actions of interest. However, as these artificial neuronal networks can also be used for military reconnaissance, is it crucial to think about methods for avoiding or impeding enemy detection or recognition by automated AI systems.

We have extensive expertise in camouflage assessment and this knowledge must now be expanded to meet the challenges posed by AI networks. However, those AIs can be deceived in a completely different way to human observers: Patterns, abstract to humans, but calculated specifically against AI can be highly effective in impeding AI's detection performance and can work as AI-targeted deception. Image depreciation, which would be no problem to humans, can also impact classification performance. Obscuring the object features that lead to the classification also works as AI-targeted camouflage. However, the features that the AI uses to classify objects are learning-data dependent, mostly obscure, and not easily accessible, as simply looking at the trained weights is sufficiently abstract that it is impossible to obtain information directly from it.

Therefore, we have used both Gradient-weighted Class Activation Mapping (Grad-CAM) and Local Interpretable Model-agnostic Explanations (LIME) to understand the classification of tanks or soldiers by different convolutional neural networks, such as GoogLeNet, Resnet or inceptionv3, which are available pre-trained for everyone. In this way, we try to identify common features that lead the AI to classify them as military objects [Image 1 and 2]. By gaining this understanding, we attempt to conceal these features, or to introduce deceptive features, and evaluate the impact on AI classification performance, with the goal of impeding or misleading it to the point where the classification of the network falls to a different object class, thus concealing the object from automated AI reconnaissance systems.

Furthermore, we evaluate the detectability of military objects using a sliding-window search method in combination with multiple neural networks as mentioned above. This detectability, i.e., the summed local class score (SLCS) for the local classification rate by the AI, serves as our camouflage evaluation rating against enemy AI reconnaissance [Image 3 and 4]. A combination of an evaluation of stealth against human observers and our self-developed software can give a comprehensive stealth evaluation that evaluates stealth performance against human observers, against AI, or against both combined.

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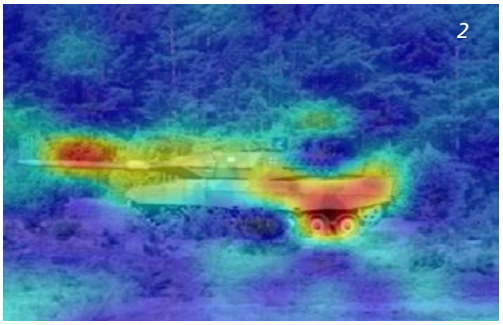





*1: Leopard 2 battle tank.*
*2: Decisive regions for AI classification as "Tank".*

*3: Tank in front of a forest edge.*
*4: AI-Detection heatmap for "Tank".*

*New laboratory for SWIR high-energy lasers.*

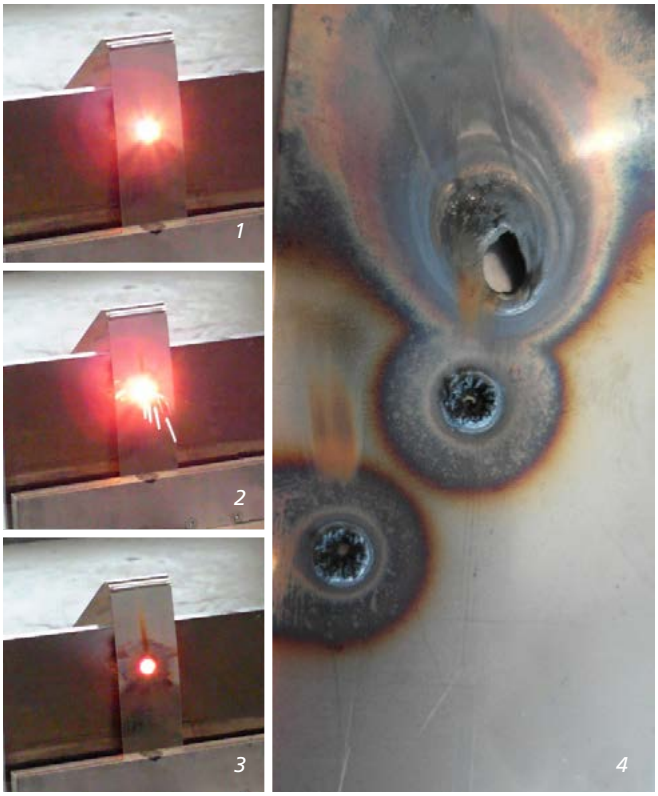
## Coherently coupled high-energy SWIR fiber lasers

Power scaling of fiber lasers in the short-wave infrared (SWIR) range by coherent coupling is a promising way to realize high-energy lasers (HEL) at new wavelengths. Taking into account the spectral dependency of molecular transmission, specific wavelengths need to be selected and novel fiber laser architectures need to be found to amplify them efficiently.

The strategy we pursue can be outlined as follows: Based on numerical simulations of atmospheric propagation, suitable wavelengths are defined. In combination with our own laser dynamics simulations, different ultra-narrow-linewidth fiber lasers and amplifiers are realized for assessing the atmospheric effects of high-power laser propagation, and specific fiber lasers and their components are developed to provide kW-class single-frequency output power. Using our own algorithms and technologies, power scaling by coherent coupling will be demonstrated and investigated. The aim is to conceive SWIR HEL laser systems that combine high beam quality with laser power far beyond the kW range.

Along that route, we have identified different wavelengths. Our research has proven power scalability of laser architectures and provided new insights into some limits. One example concerns narrow linewidths. In this case, stimulated Brillouin scattering becomes a major concern.

Based on these results and our ongoing research, we will be able to develop demonstrators and specify the necessary architecture for future laser systems with the desired characteristics.




*1–3: Temporal evolution of laser interaction with a steel plate.*
*4: Impact patterns after laser interaction with a target for different interaction times.*

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## Networked maritime surveillance and reconnaissance – an important mission for the future

In multinational defense operations, the exchange of surveillance and reconnaissance data is essential for action. In the context of naval forces, the goal is to generate and maintain a recognized maritime picture and make it available to the own forces envolved in the operation as a basis for decision-making. To that end, the 3.5-year project "Open Cooperation for European mAritime awareNess (OCEAN2020)" brought together 43 partners from 15 European countries with the aim of developing a technological demonstrator for enhanced situational awareness in a naval environment. OCEAN2020 was funded as part of the EU's "Preparatory Action on Defense Research" programm. Fraunhofer IOSB spearheaded the German contribution to the project and coordinated the international academic partners.

The challenges met by the project were manifold. In terms of technology, the aim was to achieve enhanced situational awareness by deploying and integrating diverse unmanned systems, fusing and processing the gathered data as well as presenting it in a joint Maritime Operations Center (MOC). But OCEAN2020 also addressed general topics of Persistent Wide Area Surveillance and Maritime Interdiction, and had to be accomplished in the face of numerous challenges, including its substantial complexity, a demanding timescale and the fact that it required EU-wide cooperation of end users, large industries, research institutes and small/medium enterprises.

OCEAN2020's ambition was to develop and implement the following:

- **Improved unmanned** capabilities such as the detection of small maritime targets from high grazing angles and increased level of integration, addressing UAS taking off and landing on naval platforms
- **Increased level of autonomy** of single vehicles with reduction of operator workload
- **Deployment of multiple** autonomous unmanned systems, operating as a swarm or squad
- **Automation in data fusion** at platform, combat management system (CMS) and Maritime Operation Center (MOC) level
- **Increased interoperability** and enhanced information sharing across systems and national boundaries
- **Steps** towards an EU MOC

The results were demonstrated in three virtual and two live trials. The simulated trials, part of the work package "Technology development and system simulation" led by Fraunhofer IOSB, executed the scenarios planned for the live trials, thus proving the maturity of the developed technological innovations and de-risking the live trials.

We contributed various assets to the second live trial in August 2021 in southern Sweden. Our underwater vehicle DEDAVE performed seabed mapping in support of a mine countermeasure operation. A squad of "WaterStrider" surface vehicles built a surveillance barrier that detects the approach of a hostile speed boat. Our experimental CMS fused the data provided by several partners' unmanned vehicles, which operated in the same area, into a situational awareness picture at task unit level. In addition, we provided the video processing capability, data fusion engine and situation awareness application and display for the EU MOC prototype deployed at European Defence Agency premises in Brussels and supervised the live trial operation.

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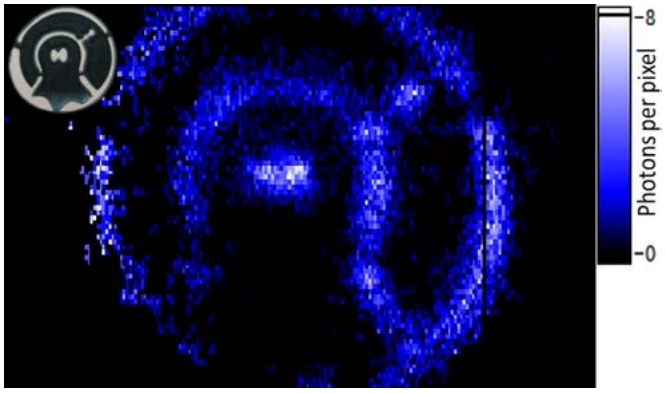
*A "WaterStrider" vehicle is being launched by the German naval forces's research vessel "Planet".*


*3D-GV recording of a dynamic scene with high depth resolution.*




*Quantum Ghost Imaging of an object with only one photon per pixel on average.*

## Active laser sensorics for reconnaissance

Military reconnaissance under adverse atmospheric conditions demands imaging techniques capable of returning high-resolution images through scattering and turbulent media. Active imaging is the method of choice for critical applications where high precision and reliability is required. Complete control over the illuminating light source enables extraction of a high level of information about the characteristics of distant targets, especially detailed range 3D information, as shown in the picture on the left. In addition to that, pulsed active imaging systems can gate the time of detection which suppresses noise and enhances visibility through fog, smoke and fire.

Gated viewing (GV) offers the perfect blend of 3D detection of non-cooperative targets in adverse conditions and detection speed. It utilizes a pulsed laser that is synchronized with a camera to illuminate distant objects of interest. A suitable timed gate only selects photons that are reflected by the object and suppresses photons belonging to its fore- and background. Thereby, you obtain a much higher target/background contrast than for a non-gated image. Furthermore, backscattered photons from particles in the atmosphere between sensor and object are not captured, thus providing advantages in conditions with poor visibility.

In a project commissioned by the German government, we are working on enhancing the performance of systems in use and developing and benchmarking modern systems for active imaging.

The systems typically operate in the short-wave infrared, retina-safe wavelength range with good properties for atmospheric propagation. The pulse energies range from several tens of microjoule in scanning mode up to tens of millijoule in flash mode. As non-detectability as well as extended coverage of spectral regions is of outstanding importance for operational use, we are investigating novel approaches to active imaging such as Compressive Sensing and Quantum Imaging.

With Compressive Sensing it is possible to detect distant objects using fewer detections compared to established active imaging systems by having control over the spatial distribution of the illumination pattern for each frame. This method requires only a single element detector for detection as the spatial information of the illuminated object can be reconstructed from the reflexion of these patterns.

Quantum Imaging has the potential to obtain images with a minimal number of single photons (picture on the right) and those systems can stay below detectability for external observers. The broadband quantum light source emits photons randomly in space and time and can thereby ideally mimic background noise. Only the sender has the key to separate real background noise from real signal via additional information from entangled photon partners. Furthermore, quantum systems are inherently hardened against hostile jamming attacks.

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# Energy, Environmental and Security Systems

## From sensor data to smart services

The Energy, Environmental and Security Systems business unit groups together all activities at Fraunhofer IOSB that address the needs of energy and water infrastructure providers, operators of environmental information systems, public authorities and similar organizations in charge of protecting and maintaining public safety and order, municipal bodies, and their subcontractors. This work involves in-depth knowledge of sensor networks and sensor data management, as well as wide-ranging expertise in data analysis, modeling, simulation, forecasting and process optimization. Other relevant areas of expertise include IT security and data protection.

We offer a wide range of services extending from basic research and technology consulting to the design and implementation of complete systems for applications such as energy management, the planning and monitoring of water supplies, and smart solutions for the real-time detection of hazardous situations based on video data.

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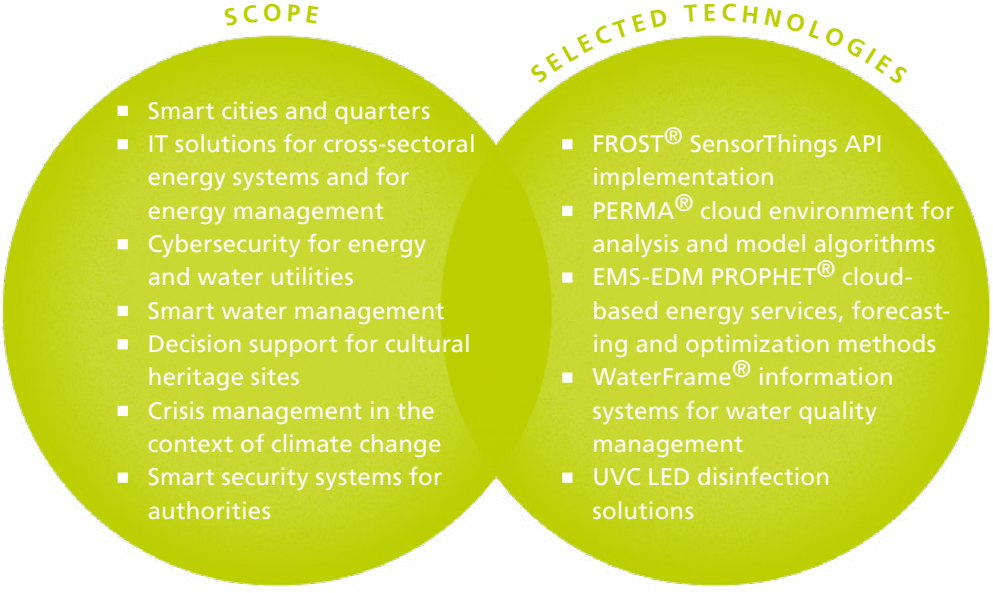
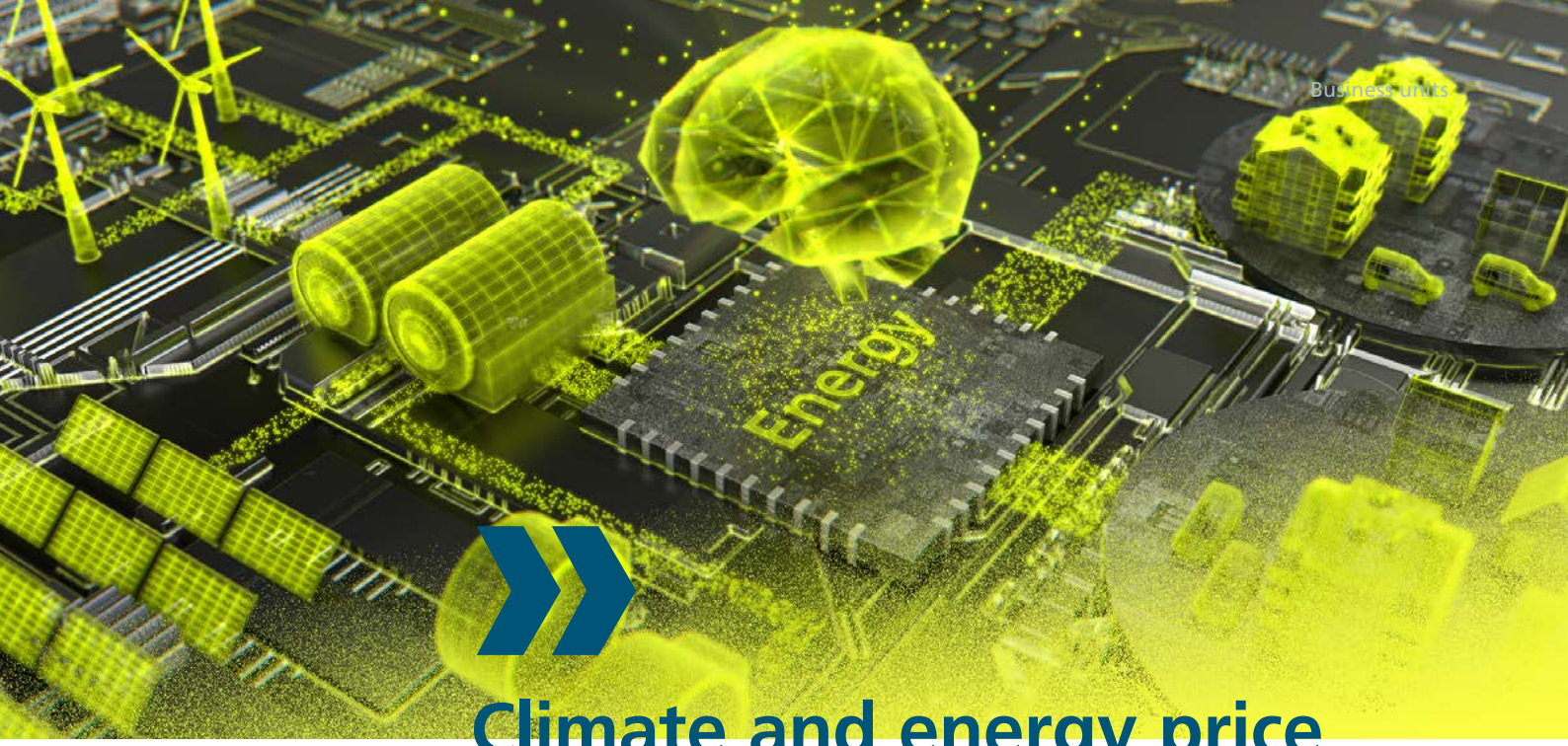
- KES
- MIT
- OPT
- SPR
- UWR
- VID






# Climate and energy price crises offer an opportunity«

Cross-sectoral coupling and cognitive systems are important building blocks for mastering the recent challenges of energy supply

**Prof. Bretschneider, as a result of the war in Ukraine, the energy transition is to be accelerated: The German government wants to generate 80 percent of electricity from renewables by 2030. Is this a realistic goal?**

Peter Bretschneider: Given the current share of around 50 percent, that is more than ambitious. The problem may not be with the technologies themselves, but also their supply availability in the face of rapidly growing demand, potential supply chain problems, cost increases, increasing shortage of skilled workers and so on. In addition to this, there are competing goals: The so-called energy policy triangle includes not only developing renewables, but also affordability and security of supply. On the other hand, the current crisis offers a unique opportunity for disruptive change that could significantly reduce our dependence on energy imports in the medium to long term. However, we must not consider electricity alone: Cross-sectoral energy supply – the coupling of the electricity, gas, heating/cooling and mobility sectors – is becoming increasingly important. Significant synergies and cost savings are possible, especially in buildings and neighborhoods, but this requires local energy storage and sophisticated energy management systems. The entire energy system is therefore changing. This is not new: Liberalization and the climate crisis are long-standing issues, but the current crisis is stepping up the pace and, among other things, it puts a new focus on energy efficiency, which can be tackled in the short term.

**What contribution can cognitive energy systems make?**

The change described above involves increasing complexity and requirements. This can only be mastered by means of digitalization. In order to operate robustly and as efficiently as possible, energy management systems including AI technology are necessary – whether for load and network loss forecasts, energy use optimization including redispatch or intelligent charging.

**What are services that Fraunhofer IOSB can offer in this context?**

Technology companies, energy suppliers and platform operators can rely on our comprehensive competence – from modeling, data preparation and automation of processes to ongoing optimization during operation, not forgetting cybersecurity, too. With our energy management suite EMS-EDM PROPHET®, we have been successful in the market for more than 20 years. New additions are the aforementioned AI solutions and cross-sector applications. With Bauhaus.MobilityLab, the growth hub SMOOD® and as part of the Open District Hub, we are involved in key flagship projects in Germany. Our customers benefit from this experience.

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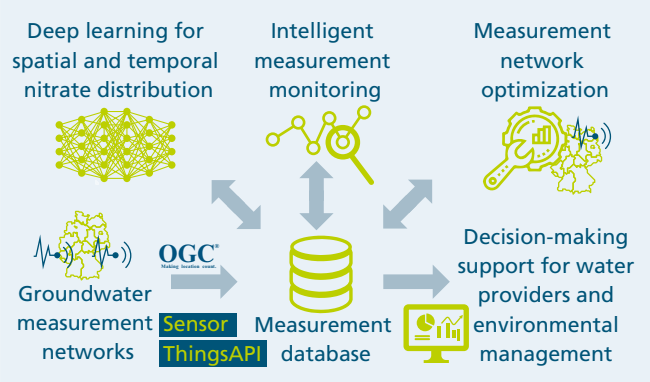


*Open standards allow to put the methods developed in research to be put into practice.*

## Intelligent systems to sustainably reduce nitrates in groundwater

The groundwater in many parts of Germany is too heavily polluted with harmful nitrates. Intelligent monitoring of measurements and improved prediction of nitrate content could help decision-makers to implement the right measures to improve the situation. That is the aim of the Nitrate Monitoring 4.0 project funded by the Federal Ministry for the Environment, with help from artificial intelligence (AI) and AI-based support systems.

Machine learning processes are being used to allow loose-knit networks to make more accurate spatial predictions of water quality than is currently possible using conventional methods. Another research task is the creation of a suitable system architecture to integrate new methods – such as ML processes – into systems that have been used by state authorities or water companies for years. This task relies on open standards by the Open Geospatial Consortium (OGC) to integrate measurements and analysis algorithms.

The project is testing how the process model from the ML4P lighthouse project (see p. 6) can be transferred to the environmental domain. This has given rise to the definition and implementation of one basic use case: To develop a random forest method to carry out an area-based nitrate forecast for Baden-Württemberg and integrate it into the architecture. To perform searches of the nitrate value time series data, provide the necessary data source for the algorithm and train the AI method and start a forecast, the project uses FROST®, the open source implementation of the OGC's SensorThings API standard developed by Fraunhofer IOSB.

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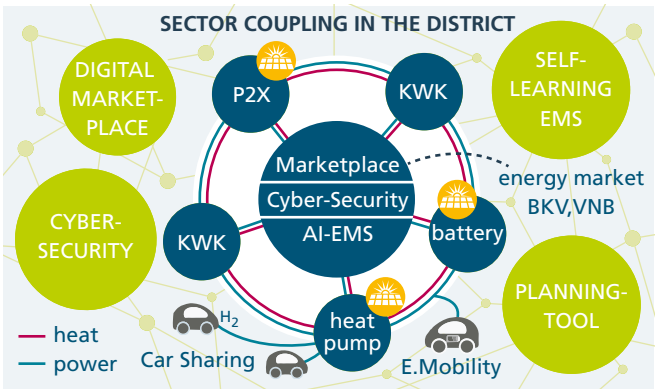
**www.iosb.fraunhofer.de/nimo**




*Hydrogen is generated from solar power, stored and then converted back to electric energy as required using fuel cells.*

## Piloting cross-sectoral energy management in a city district

It is a district like many others in Germany in terms of its framework conditions: In Bochum-Weitmar, Vonovia SE owns 232 apartment buildings from the 50s and 60s, with a total of more than 1500 flats. There are plans for their gradual renovation in conjunction with redensification of the district, including story extensions for existing buildings, to create new living space. As part of this holistic district development, the buildings will be modernized and remodeled for improved energy efficiency. What is more, the project also aims to optimize energy supply and to implement new mobility concepts as a step towards climate neutrality. The picture above shows the district's energy center.

Open District Hub e.V. – largely initiated by Fraunhofer – is using Bochum-Weitmar as a reference district. Fraunhofer IOSB-AST is a key partner in the research project, which is funded by the State of North Rhine-Westphalia, and is developing a self-learning energy management system (SEMS) to optimize the district's operation, including charging management for electric vehicles. In turn, Fraunhofer IOSB-INA has been tasked with creating the ICT ecosystem, which will integrate the components into one overarching system and provides the necessary interfaces for new, decentralized business models.

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*Example of an incident of interest to the police.*

*While barely perceptible to the naked eye, hyperspectral information can clearly identify the ripeness level of avocados.*

## Intelligent video surveillance in public places

For many years now, Fraunhofer IOSB has worked on intelligent video surveillance technology in the field of preventative policing and investigative technology. The institute develops the latest methods of intelligent video surveillance and tests them in real applications. One such example of this is our ongoing pilot project in Mannheim, which runs until 2023. In this project, we are working with the State of Baden-Württemberg and Mannheim Police Headquarters (Polizeipräsidium Mannheim) on an intelligent video surveillance system.

The aim is to develop an assistance system that alerts police officers – those who are monitoring the video images in the command and situation center – to situations that require their attention so that the officers do not have to constantly watch images from multiples cameras simultaneously. Instead, they only need to look at specific situations flagged by the system and evaluate these individually. The benefit of this is twofold: Firstly, it enables officers to intervene at an earlier stage.

Secondly, the technology has the potential to improve data protection and the general public's privacy. Once the system has proven itself in practice and relevant incidents can be reliably detected, the video images will be visible in full resolution during normal operation only after a situation of interest to the police is detected by the system. While such a solution offers huge potential, it also poses a significant developmental challenge on account of its complexity.

## Incoming quality control for food

Affordable sensors in conjunction with AI-supported analysis are opening up a wide range of new application possibilities for evaluating food. Digitally recording as many characteristics as possible and their combinations using commercial data from goods logistics plays a key role in such applications. Our portfolio now provides the option of creating digital twins (e.g., from a crate or pallet of the same products) and includes evaluations of spectroscopic features in the near infrared (NIR) range. This spectral footprint provides additional information, such as the products' internal composition.

Past data form the basis for these evaluations and the new measurements can be used to continuously improve this database as required. Our technology thus enables food to be appropriately classified and evaluated – be it identifying the apple variety at the checkout, determining ripeness during goods receipt or shortly before delivery, or checking compliance with standards or the authenticity of a food's provenance. The results are integrated into the establishment's internal IT system via digital interfaces and are made available for future transactions.

Optical detection of the quality of incoming goods using camera/sensor technology enables comparisons between individual products and product deliveries; this can be used to evaluate the possible influence of natural (e.g., seasonal) factors or different product origins. In addition, data on the relevant product/characteristic history can be quickly retrieved and easily referenced.

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# Inspection and Optronic Systems

## Assuring quality and increasing productivity by means of machine vision

The Inspection and Optronic Systems business unit is home to all the Fraunhofer IOSB activities in sensor technology, signal processing and image processing that are used for quality assurance and enhancing productivity.

Our solutions comprise, on the one hand, optical sensor systems covering the entire reflection spectrum from ultraviolet to infrared; and, on the other, IT systems for processing and analyzing signals in real time and, on this basis, providing specific information for people in the workplace or for decision-making in automated environments such as sorting systems.

These solutions are complemented by a wide portfolio of services, ranging from feasibility studies and process development to practical validation and the building of demonstrators and commercial end systems.

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Business unit development
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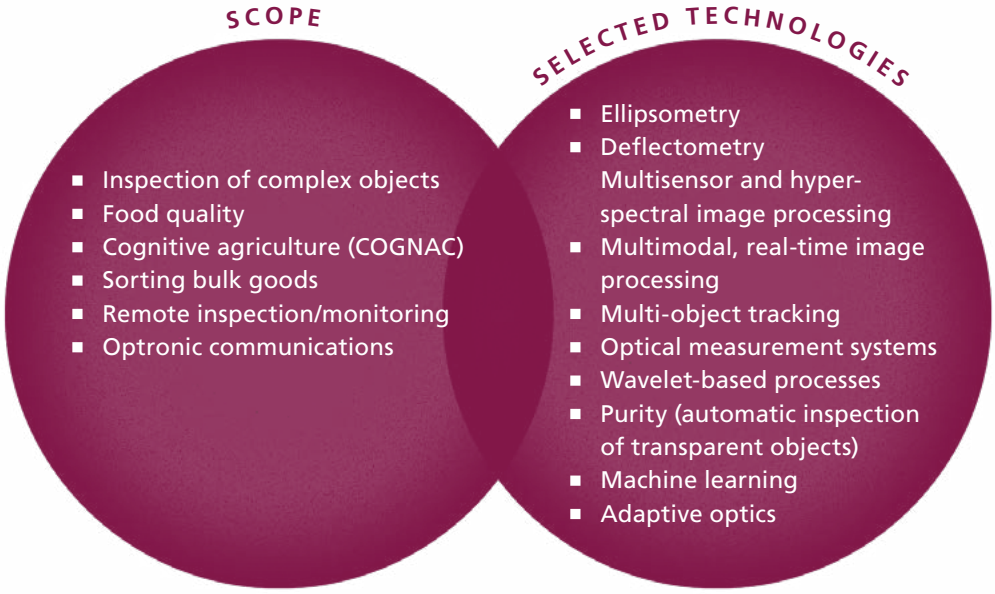
**iosb.fraunhofer.de/io**

**Departments involved**

- MRD
- OPT
- SIG
- SPR
- SZA



# Our technology helps to close material cycles«

Plastics recycling: how the IOSB's expertise in bulk material sorting and digitalization is contributing to increasing sustainability and resource efficiency

**Prof. Längle, what is the link between the technologies found in the inspection and optronic systems business unit and climate protection?**
Thomas Längle: Our skills in bulk material sorting have already been used in recycling for many years. It doesn't matter whether the material is used glass, construction waste or plastic – separating the different substances as effectively as possible is a key prerequisite when it comes to producing high-quality recyclates. With regard to plastics in particular, we need to do much better in terms of recycling if we are going to achieve the general target of climate neutrality by 2050. According to current estimates, around 50 million tons of $CO_2$ are produced as part of the plastics value chain in Germany alone each year – the majority of which is down to the fact that a good half of all used plastic is simply sent for thermal recycling, i.e., burnt. Not only would other recycling methods be more sustainable, they are also becoming more and more attractive from an economic point of view as a result of $CO_2$ pricing.

**That's why Fraunhofer is championing the vision of a circular plastics economy.**
Exactly. The aim is to significantly increase the proportion of materials that are recycled. Where that isn't possible, it's important that plastic waste is at least turned into a secondary source of raw materials through chemical recycling, replacing the need for fossil raw materials. This would keep the carbon within the economic cycle instead of releasing it into the atmosphere as $CO_2$. The Fraunhofer lighthouse project Waste4Future is developing a comprehensive approach here and our expertise is playing a key role in several ways.

**How exactly?**
Firstly, we are developing a digital twin that will map the processes and material flows comprehensively and interoperably to enable the plastics cycle to be evaluated in a transparent and digital manner. This will allow optimization across the board and the best recycling approach to be defined for each different part of the material flow – taking technical, economic and ecological factors into account. We are also making further developments to sensors and sorting technology. Commonly used sensors have weaknesses – for example, when distinguishing different black plastic materials or if parts have an internal structure. One area on which the project is focusing is therefore multi-sensor data fusion, which when combined with machine learning methods will enable materials to be identified reliably and in real time.

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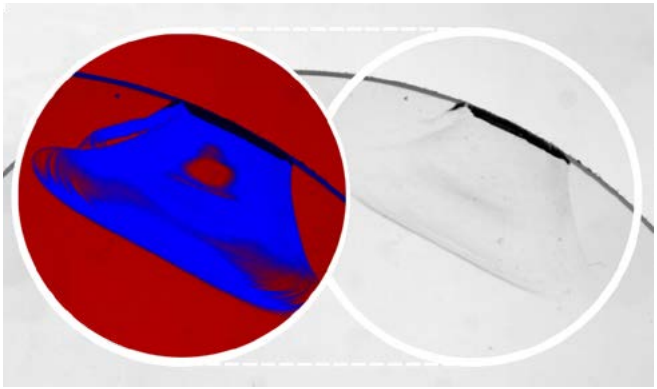
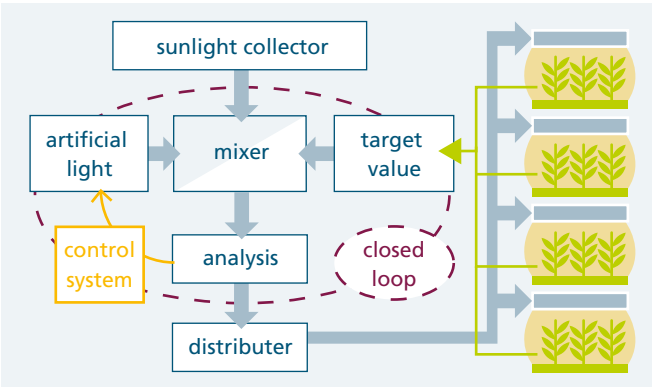


*Light field illumination reveals relevant structures in the test object more clearly than conventional bright field illumination.*




*Hybrid lighting concept for vertical farming.*

## Light field illumination for industrial visual inspections

A light field display can present different information simultaneously in different directions. Imagine a display in the center console of a car that shows navigation information to the driver while the passenger can watch a film on it at the same time. We are taking this even further and displaying different images in over 100 different directions.

To achieve this, we have built up expertise across the entire light field processing chain: from light field recording and light field processing to light field rendering. The focus in the first year was on producing a light field display. The central aspects of this were system design, calibrating the light field display, rendering light field content and taking measurements to characterize optical imaging performance. In the second year, different light field recording methods were evaluated, followed by a successful implementation of the link between light field recording and light field rendering.

We are now successfully implementing light field displays in visual inspection: A light field display is being used to illuminate objects with complex geometries using a specially adapted "light recipe" in a way that allows relevant structures to be detected with maximum contrast.

## FutureProteins – Developing a hybrid lighting system

The Fraunhofer lighthouse project "FutureProteins" combines the production of alternative protein sources in closed agricultural systems with the integrated use of all by-products to manufacture additional raw proteins. Certain plants (potatoes, wheatgrass, lucerne), insects (mealworms) and filamentous fungi such as microalgae serve as alternative sources of protein. These all contain a valuable amino acid profile well suited for human nutrition and, good application properties making them highly attractive for the food industry.

When it comes to producing plant-based proteins, the focus is on the vertical farming approach. Major advantage is that it means cultivation can take place year-round regardless of climate, making it highly efficient and resilient. The closed systems conserve far more resources than conventional farming methods: Vertical farming of plants uses just 5% of the water required for conventional methods and 50% less fertilizer, while also completely eliminating the need for pesticides.

To optimize vertical farming even further in terms of energy and cost efficiency, a hybrid lighting system is being developed at Fraunhofer IOSB to combine sunlight and LED light dynamically in a wavelength-specific way. This allows special lighting recipes to be implemented and adapted to the different growth phases of the plants (germination, root development, stem growth etc.).

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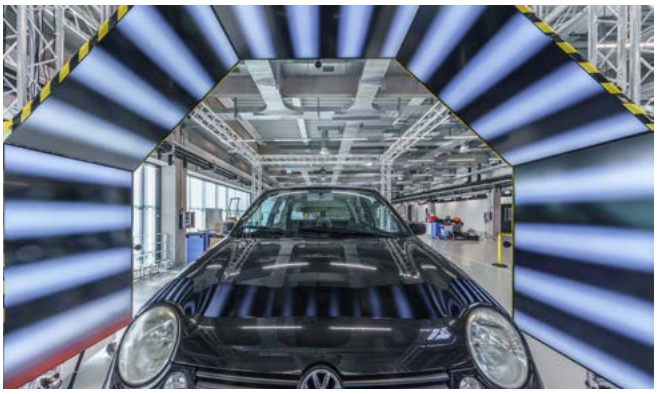

*Deflectometry makes it possible to detect even minute dents or scratches in reflective surfaces.*

## AutoInspect: Combining optical inspection results into one digital representation

Digitally fused measurement data is playing an increasingly important role in automated test procedures and downstream process control. Information about various quantities describing surfaces must be brought together at the correct location. The combination forms a weighted quality measure which allows for further analysis, e. g. with respect to user-defined quality metrics or with methods based on machine learning.

In a self-financed project, Fraunhofer IOSB has developed a large-scale, modular demonstrator for the inspection of many classes of objects. It showcases a wide variety of inspection methods for surfaces, simplifies the workflow configuration and combines the results into what might be called a digital quality twin. Results from sensors such as laser scanners, ellipsometry, and deflectometry are registered on a texture map of the object under inspection. For maximum flexibility, the objects can be moved around on automated guided vehicles (AGVs) in the inspection space past stationary sensors, as well as be inspected in detail by mobile sensors on a robotic arm, and/or by humans assisted by newly developed AR user interfaces.

The demonstrator, with example sensor systems acquiring 3D shape, dents and coating irregularities, is set up at the Karlsruhe Research Factory (see p. 8), where other processes can easily be incorporated, such as surface inspection by camera drones. This paves the way for a Fraunhofer inspection center for complex products, combining the rich expertise of several IOSB research groups into one unique solution.

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*This drone and hyperspectral camera succeeded in detecting oil reliably in the test scenario.*

## Hyperspectral pipeline monitoring from the air

To prevent environmental damage from leakages, oil pipelines are generally subject to costly testing procedures that normally require an interruption of regular operations. If aerial inspections are carried out at all, they are visual checks only. In order to identify even the smallest oil spills from the air early on, we are working with industry partners to develop an aircraft platform fitted with sensors that can deliver not only high-resolution visual aerial images, but also hyperspectral images, and can analyze them automatically.

Our main focus in this project is to develop a hyperspectral oil detection method. This involves identifying the ways in which the material-specific reflective behavior of crude oil differs from that of uncontaminated backgrounds (e.g. grass or gravel). The difficulty lies in detecting crude oil with a high degree of reliability while also avoiding false alarms triggered by other crude oil-based products such as plastics to the greatest possible degree.

In order to achieve this, a test scenario involving oil sumps, various ground substrates and crude oil types/products has been constructed to be as realistic as possible and the latest sensor and drone technology (Headwall Hyperspec Co-Aligned VNIR/SWIR combined with a DJI Matrice 600 Pro drone) has been flown over it. The results obtained so far indicate extensive detection of crude oil with only a small number of false alarms. These promising findings have resulted in further development work in an attempt to roll this out for additional scenarios.

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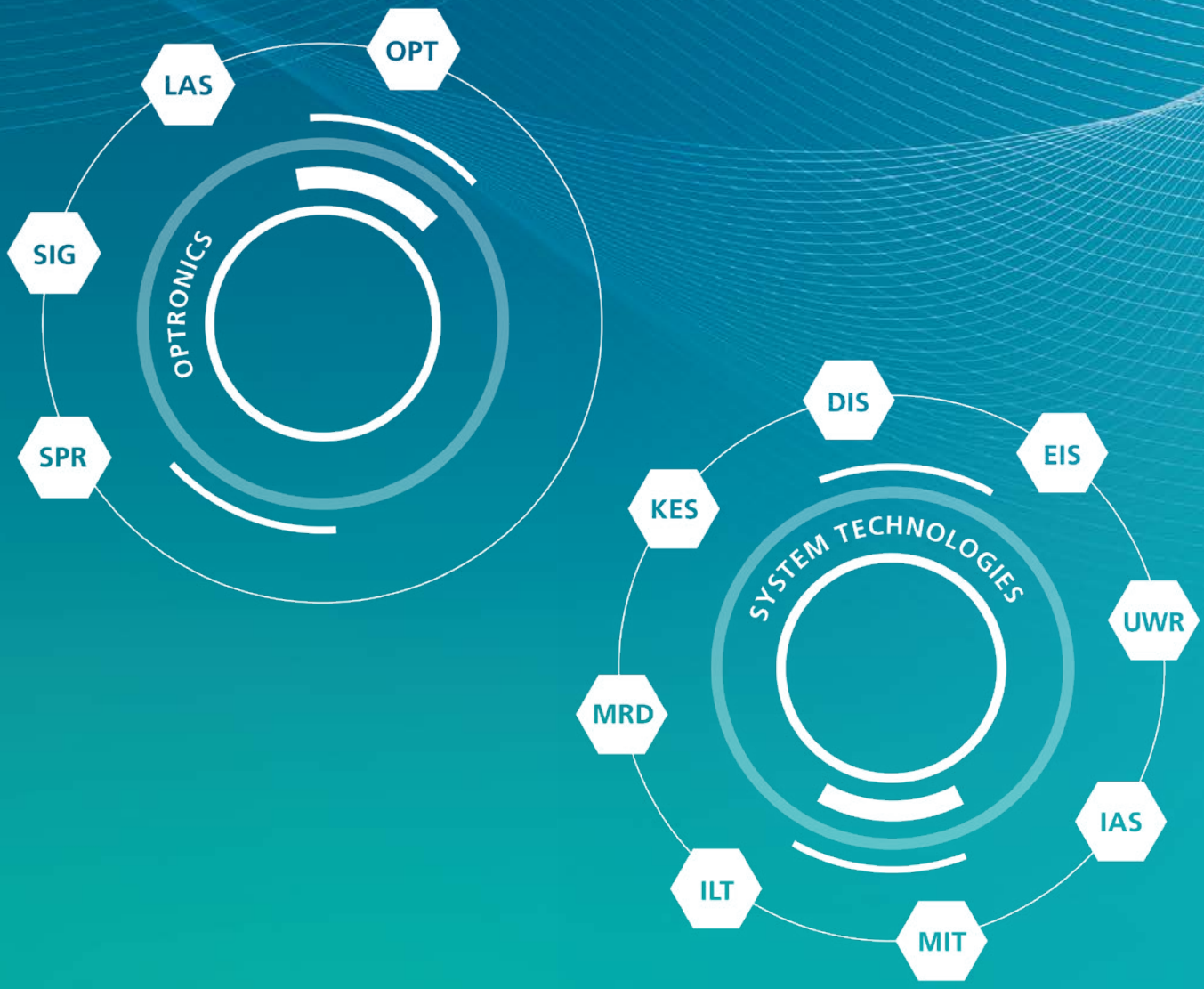
# Departments

**Our departments specialize in different scientific topics and define the institute's organizational structure.**



# LAS | Laser Technology

**The Laser Technology department researches and develops laser sources and nonlinear converters in the spectral ranges NIR, SWIR, MWIR, and LWIR, as well as specific photonic materials and components for these sources, where necessary. The focus is on the special requirements of optronic and defense applications.**

LAS

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**Research topics**

Fiber lasers
Nonlinear converters
Solid-state lasers
Crystal growth

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## Research areas and competences

Drawing on our competences in rare-earth and transition-metal doped laser materials and source architectures, we develop short-wavelength infrared (SWIR) and mid-wavelength infrared (MWIR) solid-state and fiber lasers and related components. We investigate high-power continuous wave and pulsed 2 µm fiber lasers, components and architectures, pulsed 1.6 µm and 2.1 µm solid-state lasers, and direct-emitting MWIR fiber lasers. We use our laser sources to conduct research on non-linear converters and optimize architectures for MWIR and longwave infrared (LWIR) sources to meet the demands of optronic applications. In our theoretical work, we model complex laser dynamics and resonator performance both analytically and numerically. Our goal is to enhance beam quality and wavelength coverage in high-average-power and high-energy lasers and non-linear converters and to develop new or optimized components.

## Applications, products and services

Our SWIR and MWIR laser sources can be used as direct emitters in applications such as communication, illumination, metrology, medical laser surgery and defense, e.g. as countermeasures or directed energy. They can also be optimized for pumping nonlinear converters, paving the way for high-pulse-energy laser sources at other wavelengths for such applications. We make our innovations available to other departments at IOSB, where they are used to research and develop optronic and photonic applications, such as evaluating the performance of passive and active optronic sensors and laser protection. In parallel, we investigate optical damage thresholds at specific SWIR and MWIR wavelengths on a variety of optical components (optics, laser and non-linear crystals) according to R-on-1 and S-on-1 (ISO standard) protocols. Laser damage (LIDT) measurements and power handling measurements using the sources accessible in the department are also available for external partners in joint research projects on optical components.

## Infrastructure and lab facilities

Our labs offer all facilities and equipment for modern laser research in the SWIR-to-LWIR range. This includes a variety of high-power pump sources like diodes or fiber lasers in the NIR and SWIR range, a large selection of active laser materials like crystals and fibers, a very broad set of specifically coated optics and electro-optic components for intra- and extra-cavity use as well as the necessary metrology. Besides our state-of-the-art equipment, we employ some of the most recent and sometimes very rare electro-optic metrology devices and equipment for manufacturing specific fiber-optical and optical components. Among those can be found, for example, all-fibered optical spectrum analyzers with the world's largest coverage in the MWIR and specific metrology for all-fiber systems, wavefront sensors, several plasma and $CO_2$

*View of the new high-power laser lab.*

laser splicers dedicated to the realization of specific fiber-optical components, crystal-growth equipment, and sophisticated X-ray crystal analysis devices. In collaboration with our central workshop, high-precision opto-mechanical components are realized to allow for utmost precision and robustness needed from research to fieldable laser systems.

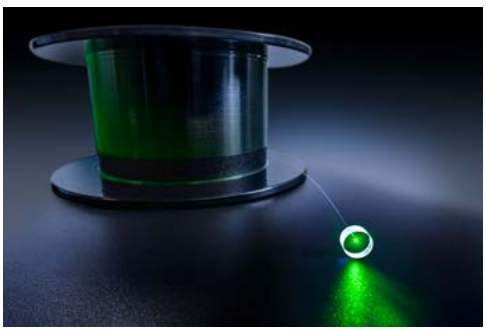
## Highlight topics

### New high-power solid-state laser lab and office building

We have inaugurated a new lab specifically dedicated to high-average-power and high-pulse-energy solid-state lasers. Together with this new space providing a down-to-class 1000 clean-room environment, new advanced equipment like multiple pump lasers, optical spectrum analyzers, and high-speed metrology has been installed. The lab serves the investigation of SWIR solid-state lasers and related research on novel laser architectures for rugged miniaturized and efficient sources. It also allows investigation and performance testing of optical components (like LIDT, thermal effects etc.). In parallel, a new office building has been officially opened to serve the staff increase in laser research while providing additional lab space for fiber investigations and propagation experiments across the southern experimental field at the Ettlingen site.

### Cooperation agreement on laser development with HENSOLDT

Based on a long-term relationship we have signed in 2021 a specific collaboration agreement with HENSOLDT, a high-tech pioneer in defense and security electronics, to develop future-proof lasers for laser-based countermeasures for self-protection systems and reconnaissance purposes. According to Countermeasures Product Manager Harald Knapp, HENSOLDT "made a very conscious decision to go with the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB in Ettlingen and their Laser Technology Department, as their expertise in the laser field and their ambitious laser roadmap are the best fit for our product portfolio. The institute has an excellent reputation in our industry." The Programme Area Manager Self-Protection Land Vehicles, Dr. Oliver Rudow, added: "With laser technology, we are advancing into a new wavelength range and higher power classes, which will enable us to develop various applications and novel products in the land, sea and air sectors. Our German customer is showing great interest in these product developments. A concrete selection decision has already been made for a first application, and we are in promising dialogue for two others."



*High-power active fiber with end cap.*

# OPT | Optronics

**The Optronics department develops and optimizes optronic systems as well as measuring technologies and evaluates their performance using both experiments and theoretical models.**

OPT

**Head of department**

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**Research groups**

Passive sensors
Active sensors
Countermeasures and protection
Optronic sensor systems
Scene simulation
Sensor simulation

**iosb.fraunhofer.de/OPT**

## Research areas and competences

We research methods and create mathematical models for designing, evaluating, and protecting innovative electro-optical sensors. With our laboratory evaluation systems and prototypes of novel sensing methods, we experiment with active and passive optronic sensors and sensor systems to evaluate their performance and possible applications. Prototypes for new imaging paradigms such as quantum ghost imaging and compressed sensing are developed. Moreover, research on High-Energy-Lasers (HEL) is performed with simulations and experiments. Furthermore, the department uses analytical and computational approaches to model sensors and the imaging process, also simulating thermal infrared (IR) scenarios to predict how the sensors will perform in different situations. In addition, we inspect, prepare, and evaluate ways to protect the human eye and electro-optical sensors (visual and IR) and to investigate how laser sources could threaten optronic systems.

## Applications and products

Our TRM4 software can calculate the performance of scanning and staring thermal imagers as well as cameras for visible to SWIR wavelengths. Valuable in both military and civilian contexts, TRM4 is adapted to changing technology and applications on an ongoing basis.

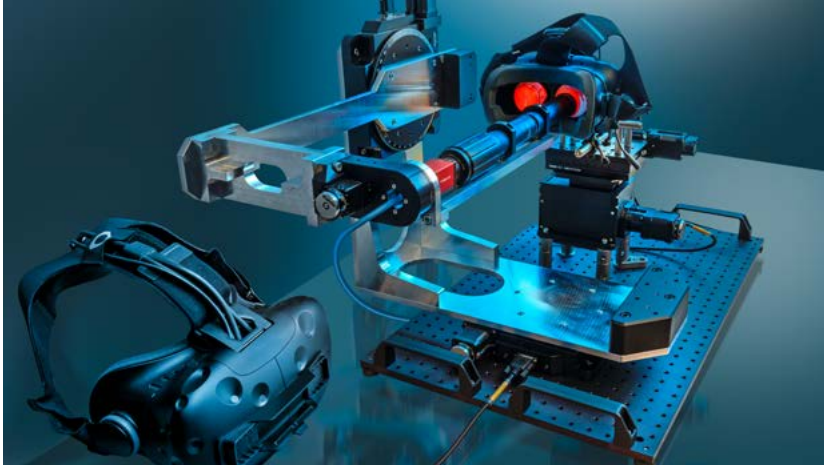
Our simulation tool OSIS simulates sensor images for user-defined imaging systems and scenes. OSIS allows for an application-oriented assessment of imaging systems and integrated advanced digital signal processing (ADSP) by using appropriate synthetic or recorded scene images. Convolutional neural networks (CNN) are used for evaluating the simulated images.

Safety requirements for (high-energy) lasers represent a unique challenge – one we have designed our dynamic water surface model OSM-IR to address. To estimate a HEL's hazard range, the reflectance of all objects in the field must be known, including surfaces subject to statistical fluctuations. The OSM-IR-Tool (ocean surface modelling IR) makes it possible to calculate these values and has been validated during field trials on open water.

Active imaging is performed with different methods and systems: compressed sensing, quantum ghost imaging and gated-viewing. The advantages of the developed prototypes are the ability to record 3D images of distant objects (> 2 km), being able to actively monitor the environment without being detected, or to capture images through a severe atmosphere such as smoke.

## Infrastructure and lab facilities

We possess labs dedicated to femtosecond laser pulse propagation, quantum ghost imaging, dazzling, and vulnerability of optronic systems (VOS), night vision, compressed sensing, gated-viewing, vibrometry, and optical



*The AR/VR device test station consists of a three-dimensional gimbal bearing an imaging system that is positioned in a way that mimics the human eye. It enables us to investigate AR/VR imaging performance for operational use.*

counter-measures (OCM). Our equipment includes a fast, high-precision IR-Scene projector with 1024x1024 pixels for calibrated camera and algorithms evaluation, test stations for performance characterization of thermal imagers and night vision devices and a laser cross-section measuring track over 500 m, 2 km and 2.6 km.

## Highlight topics

**Laser Safety Assessments for High-Energy Lasers**

Each application of a laser source requires a detailed laser safety assessment. This holds especially true for the application of high-energy lasers in the field. Even if the beam path is secured, unintended reflections from a hit object must be considered, as they can be dangerous for uninvolved persons further away.

For this reason, we perform reflection measurements on various metallic surfaces and investigate the temporal development of the reflection patterns, generated by the interaction with high-energy infrared lasers [1]. When the surface starts to melt due to the absorbed irradiation, complex reflection structures, so-called caustics, can form, which show rapidly changing intensity patterns with local hotspots. For a better understanding of these reflection patterns, and to improve laser safety assessments, we created a simulation tool to calculate these caustics at various distances from an object hit by a high-energy laser. Additionally, we use neural networks to improve the input parameters of our simulations using experimental data. The goal of these efforts is to generate a better understanding of hazards from laser reflections serving as a basis for risk assessments regarding unwanted eye damage before applying a high-energy laser in the field.

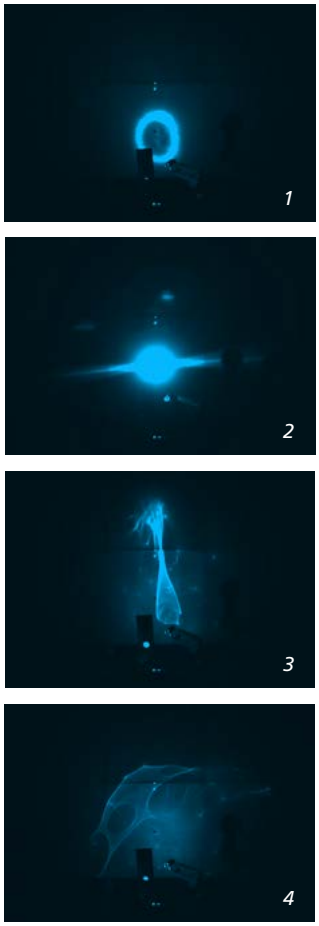
**AR/VR devices: assessment of imaging quality and impact on laser safety studies**

Near-eye displays are a technology steadily gaining significance in industrial and defense applications, e.g., for virtual and augmented reality (AR) as well as digital night vision. Considering the growing usage of such displays and their ongoing technological development, we designed a specialized measurement testbed to evaluate the imaging quality of these types of displays [2].

Our testbed enables automated measurement procedures analyzing different properties of near-eye displays, e.g., different methods of measuring such a device's modulation transfer function. Results of these measurements can support device choices for specialized applications as well as deliver input for the advancement of the simulation of the optoelectronic imaging chain with TRM4 and OSIS.

Apart from the assessment of imaging quality, we also investigate potential new applications of such devices. For example, AR devices allow for a new way to simulate laser dazzling without having to use real laser dazzlers [3]. This is especially useful to investigate the deterioration of human performance, e.g., in terms of the ability to drive a vehicle or task performance, like shooting precision. Additionally, it offers a lot of potential for training on how to react to being dazzled.

Augmented and virtual environments are an innovative field with an important future that we want to help shape.




*Time-dependent reflection characteristics of a near-infrared laser beam after hitting a metallic target. Initially, there is a geometrically confined reflection in a defined direction (1). Then, ring structures can emerge due to physical stress on the target (2) and when the target starts to melt, pronounced caustics form in the reflection pattern (3-4).*

**1** M. Henrichsen et al, "Laser safety assessments supported by analyses of reflections from metallic targets irradiated by HEL light," Appl. Opt. 60, F71-F87 (2021)

**2** C. Günther, M. Henrichsen, and S. Kessler, "Prototype measurement setup to assess near-eye display imaging quality," Proc. SPIE 11866, 118660J (2021)

**3** M. Henrichsen et al, "Simulating laser dazzling using augmented and virtual reality," Proc. SPIE 11867, 118670F (2021)

# SIG | Signatorics

**The Signatorics department specializes in optimizing the performance of electro-optical systems and in technology for signature assessment and management within the propagation environment.**

SIG

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**Research groups**

Warning sensor systems
Optics of the atmosphere
Signature management
Signature assessment
Adaptive optics

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## Research areas and competences

Our research focuses on warning sensor technology, adaptive optics, evaluation, and the management of optical signatures and optics of the atmosphere. We characterize the environment to better understand its interactions with system performance and are experts in the propagation of light. We identify adverse effects on systems operating within the UV to the IR spectral bands and develop hardware and software to overcome these effects. Our expertise in multi-spectral threat signatures allows us to design, assess, and optimize innovative sensor technology. We research and develop techniques to minimize one's own signature (camouflage) and generate false signals (decoy).

## Applications, products and services

Our expertise has both civilian and military applications. We develop innovative approaches that are driven by advances in detector technology (e.g. multi-spectral sensors) to warn against projectiles and missiles. In addition, we design sensors for satellite-based monitoring systems and conduct field trials with passive and active sensors in maritime and terrestrial environments. We also devise measurement methods and equipment as well as innovative adaptive optics systems with applications in both sensor technology and free-space optical communications. Our laboratory and field measurement equipment enables the determination of optical materials and system properties within the full spectral range.

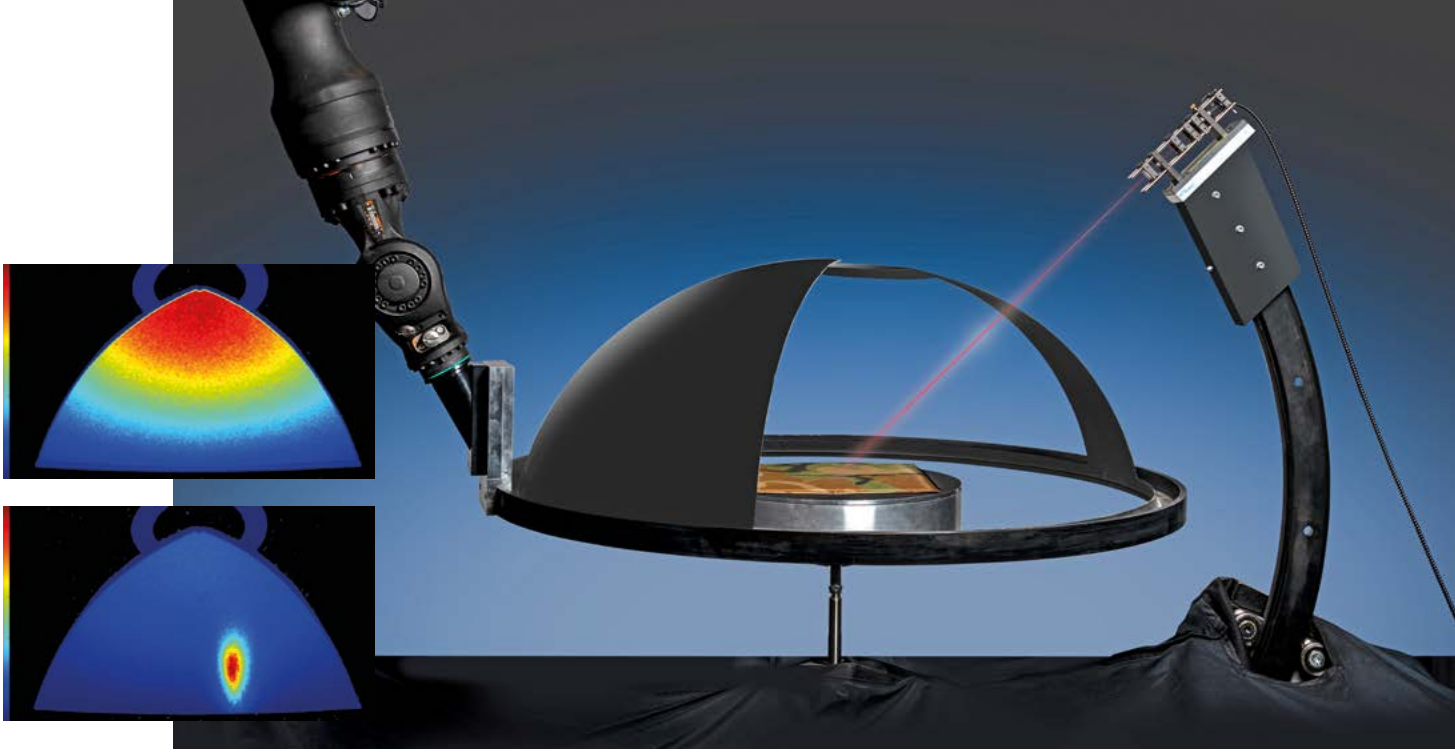
## Infrastructure and lab facilities

Planning and conducting field trials are important aspects of our work and they are based on our own ground, sea, and air-based sensor systems and measurement methods. Our adaptive optics test stations allow for the emulation and correction of atmospheric and underwater turbulence. In our underwater turbulence laboratory, we carry out experiments with exotic states of light propagating in water, which has applications in covert underwater communications. We operate two laser links, of 400 m and 7000 m lengths, and can transmit data at GBit/s bandwidths in free space, using coherent modulation and reception. We also operate a robot-driven setup to automatically measure bidirectional reflectance distribution functions (BRDF). Finally, our environmental simulation lab lets us account for solar radiation, sky coverage, and crosswind in assessing signatures.

## Highlight topics

### Efficient optical surface reflection measurements with a dome

Interest in the Bidirectional Reflectance Distribution Function (BRDF) of materials has been growing steadily for several years. It describes the directional interaction of radiation with matter and its knowledge is highly desirable in several industries, such as the video game industry, paint and coating manufacturers, and the military. Once known, a simulation can be performed that replicates the material



*Above: Image of the hemispherical sector placed around a sample. Below: Image of material reflected radiance onto the dome.*

behavior under arbitrary illumination sources and configurations. The measurement of this high-dimensional function requires special equipment, so-called gonioreflectometers, which are used to determine the BRDF according to the traditional pointwise sampling method. However, this is a difficult and very time-consuming procedure.

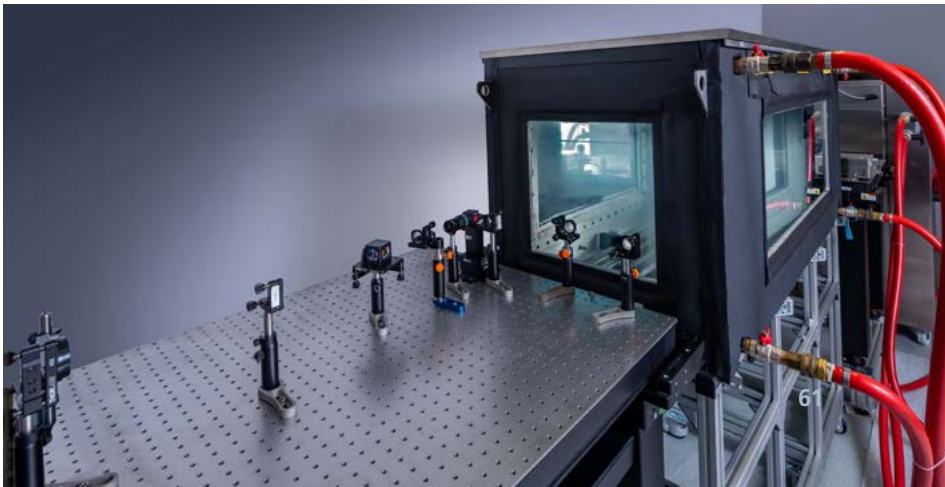
We implemented a new measurement method in a robot-based gonioreflectometer. It is based on imaging capture of the sample reflectance. This method is over 300,000 times faster than the sequential sampling method. Nevertheless, to take full advantage of this, a few drawbacks must be compensated. The directional information must be mapped using a mirror reference measurement. This allows for the same angular representation as with the sampling method. Possible cross-reflections within the hemispherical sector must also be quantified and compensated. These two points are research topics that are currently being investigated and explored.

**Underwater optical wireless communications**

The oceans are Earth's final frontier. Their exploration will require not only R&D activities in robotics, material science, and navigation, but also in communications. Underwater exploration will generate a vast amount of data that should be reliably transferred between unmanned underwater vehicles, be-tween submarines and between either of the former and their ground stations. For many years, sound has been used as the primary method for underwater communications, with a low data transmission rate. A higher bandwidth can be achieved with visible light, as other wavelengths of electromagnetic radiation get severely absorbed by water. However, the underwater environment presents challenges for the propagation of laser beams. In clean ocean water, extinction due to absorption and scattering limits the useful range of underwater communications. Additionally, underwater optical turbulence stemming from minute differences in water's refractive index and salinity perturbs the laser beam.

The new Underwater Communications Laboratory has been set up at the Ettlingen site to study and compensate for this effect. Experiments have been carried out in a 1.5 meter long water tank. For the first time, real-time correction of underwater turbulence through the use of adaptive optics has been demonstrated in scenarios emulating propagation over approx. 100 meters in clear ocean water. By using adaptive optics, one can expect to decrease the number of errors in transmission by several orders of magnitude.

*Our 1.5-meter long 500 liter tank with an adaptive optics experimental setup as well as heating and cooling device for controlled turbulence generation.*



# SPR | Visual Inspection Systems

**The Visual Inspection Systems department develops and delivers systems for automated visual inspection, performing tasks such as sorting bulk goods, inspecting food, and providing quality assurance for transparent and reflecting materials.**

SPR

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**Research groups**

Sorting systems for bulk goods
Inspection of complex products
Food quality and agriculture

**iosb.fraunhofer.de/SPR**

## Research areas and competences

Our work revolves around using optronic sensors and machine vision for characterizing and inspecting various materials and objects. We work with high-resolution line-scan cameras of various types (color, UV, and imaging NIR), 3D area array sensors, laser scanners, hyperspectral technology and NIR point spectroscopy sensors. The imaging equipment is customized for each specific task and relies heavily on folded beam paths and LED flash illumination. Our expertise also includes high-performance system architectures with specially developed frame grabbers and image exploitation algorithms. These are essential given the inspections' high throughput rates and the need to build reference databases. Our solutions are currently in use in a great number of factories where they perform tasks such as quality control.

## Applications and products

We develop systems that sort bulk goods automatically. They are used in recycling (e.g. glass, plastic, and construction and demolition waste), mining (minerals), and the food industry (for purifying coffee, tea, grains, grapes, and other products). Other systems we have designed can inspect surfaces for defects, inspect and classify transparent materials of all shapes, measure the color of granulates, and inspect blister packs. Our products are used in industrial settings around the world. Currently, we are working on a mobile food scanner that uses NIR spectroscopy to check the composition, freshness, and quality of foodstuffs.

## Infrastructure and lab facilities

In order to realize a machine vision system that is capable of performing a given task as well as to determine how accurate and how resource-intensive the solution will be, our department operates an image exploitation center and a cross-application multi-sensor lab. Our wide range of experimental facilities includes hyperspectral imaging equipment for inspection within the whole wavelength range from UV to NIR, experimental systems for sorting bulk goods (on a belt, with a chute, or in free fall), measurement setups for 3D and surface inspection, equipment for characterizing materials, and a cleanroom for sensitive components.

## Highlight topics

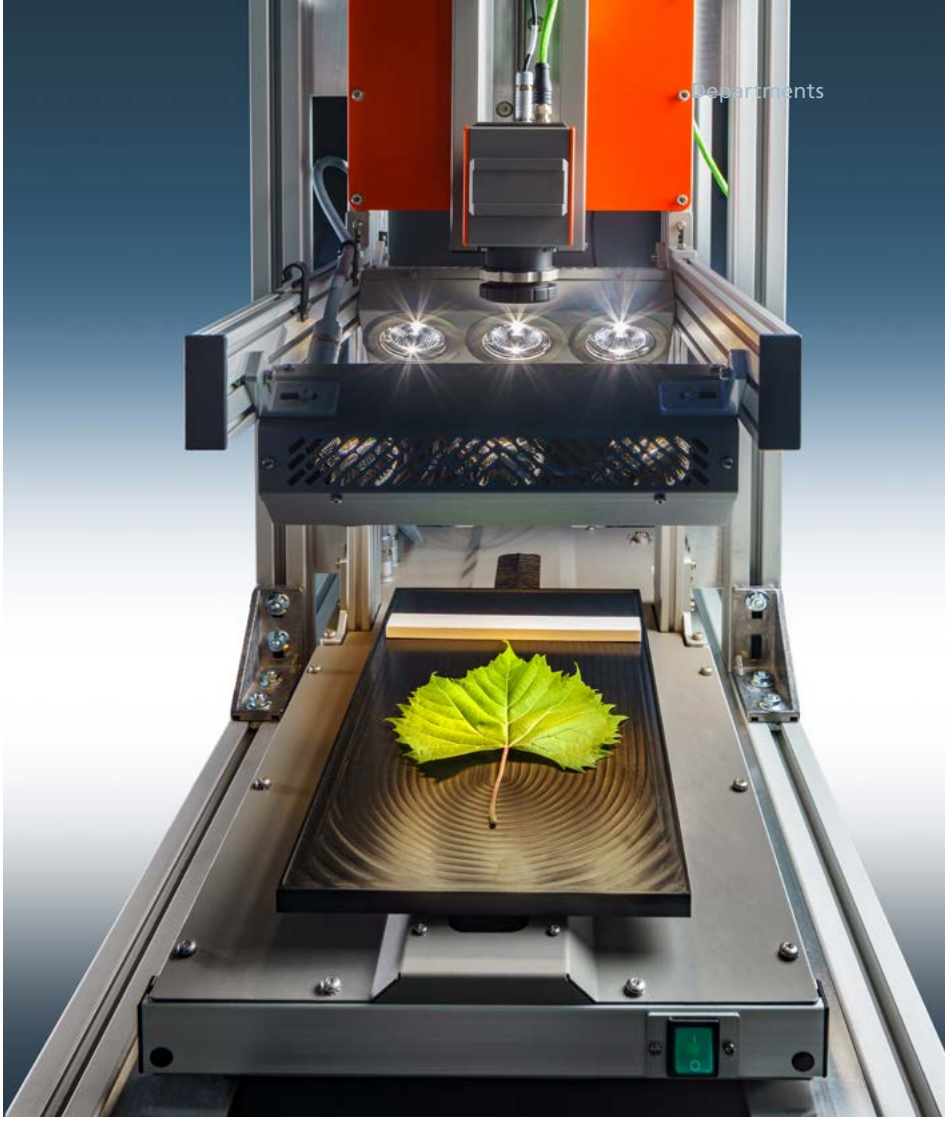
**Digitalization and artificial intelligence in viticulture**
For millennia, grapevine has been among the most important cultivated crops in Europe. Yet, digital technology has the potential to substantially assist the winemaker in terms of quality, efficiency, and flexibility. Three of our current research projects focus on using spectral sensing and specialized cameras in combination with AI.

Firstly, in times of climate change, finding the optimum harvest time may be challenging.

Therefore, a hand-held spectral sensor is used to measure the ripeness of berries based on their reflectance spectra. During harvest, it is desirable to only pick ripe and healthy grapes, which could be automated by AI-based imaging systems and has already been successfully demonstrated. Spectral sensors embedded into the tank of the harvester allow for in-field quality selection.

Secondly, we investigate imaging applications for yield prediction. As soon as flower buds appear in the vineyard, they could be automatically counted using image processing to compute an initial yield estimate. This estimate could regularly be updated until ripe berries are considered for a final prediction, resulting in increased planning reliability for the winemaker.

Thirdly, just like other organisms, grapevine is constantly threatened by diseases. In order to facilitate early detection and prompt countermeasures, we work on evaluating the spectral fingerprints of infected and healthy plants. For this, a multispectral camera specifically adapted to the disease symptoms is to be configured.



*Hyperspectral camera for recording the health status of plants.*

While these projects focus on grapevine, the methods and algorithms could be transferred to other crops in the future and thus provide a valuable contribution to the automation of in-field phenotyping.

**Waste4Future: high-quality plastic recyclates from sensor-based waste sorting**

Plastics recycling – one of the greatest challenges of our time – is attracting huge amounts of attention in the media and society as a whole. Political regulations such as $CO_2$ pricing are providing incentives for a truly circular economy. Our sensor-based sorting technology lays the foundation for producing high-quality recyclates in the mechanical and chemical recycling process. This is because the composition of the input material has a significant impact on the final product. There are a whole range of variables to consider, for example the proportion of different polymers, material changes to the plastic due to aging, any flame retardants contained therein and even the color of the plastic.

Based on data captured by sensors and using fast switching pneumatic valves, our facilities therefore sort plastic waste by material and, where necessary, color. The Fraunhofer lighthouse project Waste4Future, which involves six other institutes, is currently focusing on a multi-sensor system to enable robust material characterization. The aim is to develop a system that can also characterize black plastics (colored using soot), which cannot be detected using NIR hyperspectral imaging in the short-wave infrared range. The potential of the terahertz sensor technology that will be used has already been demonstrated in a predecessor project. Machine learning methods for sensor data fusion should also allow for test objects to be sorted in real time according to their age. The end result is high-purity input material, which in turn produces high-quality recyclates.

*Plastic waste is mostly a disordered material flow. The aim is to turn it into partial streams for a suitable processing route.*

# KES | Cognitive Energy Systems

**The Cognitive Energy Systems department develops pioneering technologies in the field of energy systems engineering in the areas of energy informatics, energy logistics and cognitive energy systems – as an essential contribution to the transformation of the energy system.**

KES

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**Research groups**

Electrical energy systems
Cross-sectoral energy systems
Energy informatics
Cybersecurity for energy and water

**iosb.fraunhofer.de/KES**

## Research areas and competences

We are ideally placed to meet the challenges of the energy transition, especially in the electricity market, with our specific expertise in cognitive and integrated energy systems, energy informatics, AI-based decision-support systems, system analysis and design, digital twins and convergent IT infrastructures. This shift, which is increasingly driven by power generated from renewable energies, is founded on new integrated approaches to coupling the electricity, heat, gas, production and e-mobility sectors. We also offer services related to cybersecurity for energy and water supply, which are becoming increasingly important in the course of the digitalization of energy and water supply systems.

## Applications, services and products

For the benefit of our customers, we develop and test novel and customized methods, solutions and services in the fields of energy forecasting, energy use optimization as well as simulation and operation management of electrical and cross-sector energy systems. Over 30 energy providers in Germany use our EMS-EDM PROPHET® software for a range of significant processes, including the forecasting of energy demand, management of balancing groups, power plant dispatching, and market communications. In partnership with the Fraunhofer Academy, we offer training courses in energy data analysis and cybersecurity. Our spin-off venture AMPEERS ENERGY GmbH develops full digital solutions for managing locally generated electricity supplied to tenants. In 2019, we were able to secure our participation in three major energy research projects, each with a multi-million-euro budget: the growth hub "smood – smart neighborhood," the AI innovation project "Bauhaus.MobilityLab Erfurt" and, in cooperation with the nonprofit organization Open District Hub, a number of neighborhood projects. In addition, we are also involved in "ZO.RRO – Zero Carbon Cross Energy System," a project in Thuringia that aims to develop a system solution for a carbon-free energy supply.

## Infrastructure and lab facilities

We have excellent research facilities, located in the new building at the Fraunhofer site in Ilmenau. The new labs include an energy market lab, a control technology lab, an IT security lab and an energy technology lab.

## Highlight topics

**Real-time simulation of cross-sectoral energy systems in the InSignA High-Performance Center**

With a total of five Fraunhofer institutes and seven specialist departments at Ilmenau University of Technology, the new Intelligent Signal Analysis and Assistance Systems (InSignA) High-Performance Center brings together the expertise of these different organizations in the

field of signal analysis and assistance systems, enabling forward-looking technology transfer that strengthens the regional economy.

As a part of the High-Performance Center, we are participating in the pilot project "Design and implementation of a cross-institutional, real-time-capable simulation platform for cross-sectoral energy systems." Germany's ambitious climate protection targets make the cross-sectoral consideration of energy flows more important than ever. In light of this, the pilot project will collect energy data and, by means of innovative sensor systems, environmental data for selected buildings at Ilmenau University of Technology and use them in the real-time simulation platform.

Due to increasing electrification (e-mobility, heat pumps) in the residential sector, automatic detection of faults in the power grid (anomaly detection) is becoming more and more important – another field we are researching at InSignA. The real-time simulation platform, which is currently under construction, also serves as a basis for joint research projects, as a showcase demonstrator and as a platform for implementing customer solutions.


*The "InSignA" High-Performance Center combines the strengths of Fraunhofer, the Ilmenau University of Technology and the regional SMEs and industry in the field of intelligent signal analysis and assistance systems.*

**ZO.RRO: Zero Carbon Cross Energy System**

Germany is off to a good start on its journey to renewable power generation. As the nation's exit from fossil fuels enters the second phase, the focus is shifting toward reducing energy consumption and carbon emissions. This is where the ZO.RRO (Zero Carbon Cross Energy System) research project comes in. The project develops approaches and solutions for a $CO_2$-free energy supply system using the example of the Free State of Thuringia by taking a cross-sectoral view of electricity, heat and gas supply and also considering the provision of the necessary system services. Studies have shown that these system services, which are necessary to ensure system stability, are responsible for 20 percent of carbon emissions. To bring the energy sector and industry together in this project, an interdisciplinary consortium has been formed comprising the departments of Electrical Energy Supply and Energy Use Optimization at Ilmenau University of Technology, Fraunhofer IOSB-AST, Nordhausen University of Applied Sciences, the Engineering Bureau for the Energy Sector (IfE), the KoCoS Technology Group, the Thuringian Renewable Energies Network (ThEEN) and the municipal utilities partnership Trianel.

The models that we have developed as part of this project consider an innovative scenario characterized by renewable energies, storage and hydrogen technologies, as well as a conservative scenario that includes power-to-gas and gas power plants. An optimization model shows the technologies that will need to be installed in Thuringia in the future in order to keep greenhouse gas emissions to a minimum. Our newly developed $CO_2$ monitoring tool allows companies to monitor their $CO_2$ footprint in detail according to their current energy mix and visualize $CO_2$ emission forecasts. The necessary data is provided by the ZO.RRO box developed as part of the project. A special piece of software makes it possible to make use of existing flexibilities to shift gas, heat and power loads to minimize carbon footprints and offer zero-carbon system services.

The potential users of these hardware and software solutions include municipal utilities, accommodation services and ministries as well as businesses. In phase two of the project, which is scheduled to start in 2022, the solutions will be developed further and tested by participating businesses.


*ZO.RRO Digital User-Interface.*

**Website**

https://s.fhg.de/insigna

https://www.zorro-thueringen.de/en

# DIS | Digital Infrastructure

**The Digital Infrastructure department researches and develops technical solutions and integrated environments for IoT (Internet of Things) applications for use in smart factories and smart cities.**

DIS

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**Research groups**

Intelligent sensor systems
Industrial communication & IoT
Cybersecurity in production

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## Research areas and competences

We build the foundations and develop architectures for the (industrial) IoT. In order to provide context-sensitive situation analyses, computer systems must be able to monitor the cyber-physical system using sensors and localization. We design smart sensor systems for machinery and equipment, work on real-time data processing and construct software-controlled networks with flexible and integrative protocols. The aim is to provide the right quality of information, thereby enabling efficient interaction between people, products, machines and infrastructure. We research and develop network solutions that structure and transfer information in real-time. Our network architectures all feature flexibility, interoperability, speed, intelligent network controls and security.

## Applications, products and services

We develop various kinds of systems for indoor localization, object recognition and smart sensors. We also develop applications for the industrial internet. These include real-time Ethernet and industrial wireless solutions, real-time middleware, and network management and system integration solutions. In the field of cybersecurity, we design hardware and software that secures critical infrastructure in industrial environments. In addition to R&D services, we also offer hands-on training and consultancy in all of these areas.

## Infrastructure and lab facilities

In cooperation with the Machine Intelligence department and the University of Applied Sciences and Arts Ostwestfalen-Lippe (OWL), we run two living labs in the OWL high-tech region, both of which offer a full range of services to support various customers on their journey of digital transformation: SmartFactoryOWL, a living lab for Industrie 4.0 technologies, and Lemgo Digital, a participatory Smart City living lab for medium-sized cities (20,000–100,000 inhabitants). In partnership with the Fraunhofer Academy, we also offer courses at the Cybersecurity Training Lab in IT/OT security for production, tailored to the needs of small and medium-sized enterprises.

## Highlight topics

**5G in industrial use: Application Center Lemgo**

In production, the new mobile communications standard 5G means wireless real-time communication between machines and devices, the interlocking of process steps coordinated to the millisecond. The greatest added value of 5G lies in wireless transmission with high availability and low latency. Companies have the option of setting up the new technology in their production facilities with a so-called 5G campus network, if necessary without an interface to the public network, such as the Fraunhofer 5G Application Centers. The participating Fraunhofer institutes already operate 5G application centers and

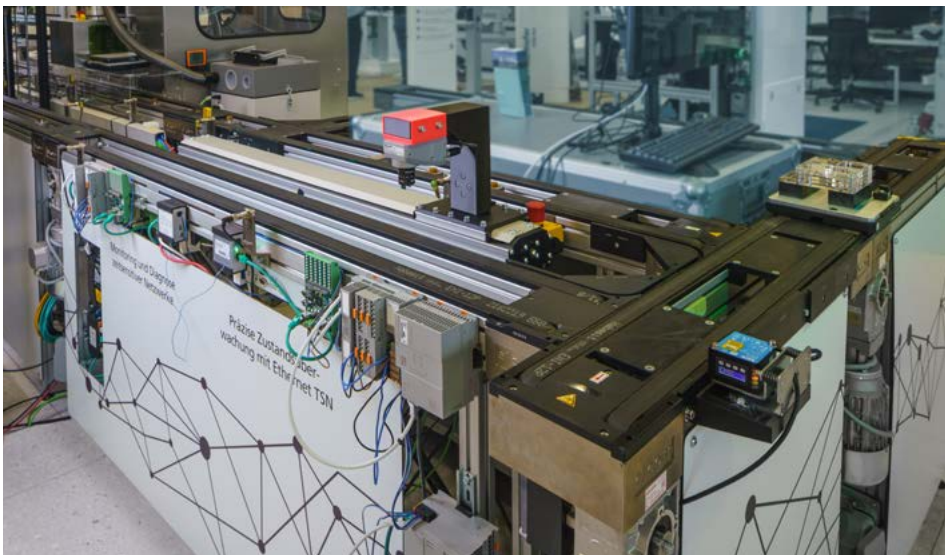

*3D lift system for automatic and reproducible testing of 5G and localization technology.*

test centers for digitalization in the fields of automation, products / devices, cities, mobility and production. For the first time, the research partners are now linking up across locations. In addition to remote maintenance of production machines, other scenarios could include automation from the cloud or the use of the latest technologies such as millimeter waves in industrial applications.

**5G in future mobility: 5G SIMONE and MonoCAB**

5G offers many possibilities for quickly analyzing large amounts of data and optimizing processes in various fields of application. One of several new projects funded in the context of North Rhine-Westphalia's 5G.NRW initiative, with a budget of up to 2.6 million euros, is "5G SIMONE". Here we collaborate with the local technical university, TH OWL, and industry partners to research the potential of 5G with respect to "closed-loop control" applications in the context of public transport. 5G SIMONE is closely associated with another project: MonoCAB aims at constructing and testing self-propelled monorail shuttles driving on conventional railroad tracks. These innovative vehicles require gyro stabilization and appropriate control technology, which in turn relies on real-time information from the environment and other vehicles. 5G promises to adequately meet the high latency and reliability requirements and still leave capacity for infotainment applications and for user interaction. The project will also investigate how supplementing public 5G networks with private 5G cells can meet the requirements without gaps.

*Test of Ethernet TSN prototypes on a machine in the SmartFactoryOWL.*



# EIS | Embedded Intelligent Systems

**The Embedded Intelligent Systems department researches and develops systems engineering solutions in the form of embedded real-time systems for various applications. We also use AI technologies for this purpose.**

EIS

**Head of department**

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**Research groups**

Cognitive autonomous systems
Smart UV-systems

**iosb.fraunhofer.de/EIS**

## Research areas and competences

The automation of mobile machinery is one of the focal points of our work. To this end, we create sensor concepts for mobile working machines. We develop sensor data fusion algorithms for environmental perception, mapping and navigation so that mobile robots can be located and trajectories can be planned. We develop and employ AI, sensor data fusion, advanced control algorithms and corresponding simulations.

Another area of focus is the application of new UVC LED technologies for disinfection. For example, our researchlooks at how UVC LEDs can be employed to inactivate viruses, bacteria and mold on surfaces as well as in flowing media. We optimize how these UVC LEDs are arranged and controlled. We use extensive multiphysics simulations to couple radiation propagation with the flow of liquid and gaseous media to determine the radiation dose for individual volume elements of these flowing media. We use these simulations to develop, evaluate and implement innovative UVC disinfection systems, and we can test these systems in our laboratory as well as in operational environment with suitable measurement technology.

## Applications, products and services

For our customers we provide the full range from consulting and feasibility studies to the implementation of near production-ready prototypes. In this respect, we focus on the areas of embedded electronics, automation solutions for mobile systems and UV-LED applications.

## Infrastructure and lab facilities

Our high-quality laboratories are fitted with a wide range of equipment for the manufacture, assembly and testing of electronic systems. Rapid prototyping systems enable us to implement ideas quickly. In the hardware-in-the-loop (HIL) test laboratory, we are able to evaluate localization and vehicle control systems using our precise reference measurement technology. The measurement equipment in our UVC laboratory allows us to evaluate and test UVC systems.

## Highlight topics

**UVC disinfection for ambulances**
Together with our industrial partner BINZ Ambulance- und Umwelttechnik GmbH, Fraunhofer IOSB-AST developed an interior disinfection solution for rescue and ambulance vehicles based on UVC LEDs. The system is integrated into the roof of the vehicle and disinfects the air and surfaces inside the vehicle fully automatically. Most pathogens are 99.99 percent inactivated within 10 minutes; even the rate of inactivation for the SARS-CoV-2 virus is as high as 99.999 percent. This innovative disinfection system supports manual disinfection and thus drastically reduces the

*Living laboratory for mobile working machines: Off-road section with all-terrain forklift and drone.*

downtime between the two possible uses. The disinfection process can also be performed on the way to the next emergency.

**Living lab for automated working machines**

The use of automation solutions is growing also in the field of mobile working and utility machines. In addition to conventional assistance systems, there is a growing demand from users for additional support functions that require an increased degree of autonomy from vehicles: If a car can drive itself, why can't a mobile working machine?

As systems become more complex and new types of sensors emerge in the market, established simulation methods are quickly pushed to their limits. For this reason, we are setting up a living lab at the Ilmenau site in order to carry out tests on vehicles in typical practical applications. Roadways and movable elements have been set up near the existing integration hall on a fenced area to simulate a wide range of scenarios and validate algorithms for new autonomous vehicles.

The living lab also features comprehensive measurement and sensor technology. Our customers have at their disposal: 3D-LiDAR sensors, reference measurement technology such as DGPS and gyro systems for vehicle dynamics measurements, optical laser trackers and high-performance communication systems. Other mobile working machines such as field tractors, forklifts, driverless transport systems and municipal vehicles are also be available at the living lab for the purpose of testing and validating new types of mobile working machines in combination with established, partly automated systems.

*The system on display at the "proVention" COVID-19 trade fair in Erfurt, Germany.*

# ILT | Information Management and Production Control

**The Information Management and Production Control department develops open system architectures and software components to create secure IT solutions that satisfy our customers' needs in fields of applications such as Industrie 4.0, smart cities, environmental data and crisis management.**

ILT

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**Research groups**

Information and knowledge management
Modeling and networked systems
Smart factory systems
Architecture and information systems
Industrial cybersecurity
Cyber-physical distributed systems
Geospatial data analytics and management

**iosb.fraunhofer.de/ILT**

## Research areas and competences

We implement open, innovative, customized software solutions that drive new paradigms in the Industrial Internet of Things (IIoT) and in Industrie 4.0. Building on agile methods in requirement analysis, system and software engineering, and recognized architectural and communication standards, our work encompasses the sectors of industrial production, environment, health, risk and crisis management, resource efficiency, and security. We design open architectures and solutions based on methods of artificial intelligence and machine learning, AI systems engineering, digital twin management, semantic annotation, and the fusion of raw sensor data into meaningful information to support decision making. We are also leaders in IT security concepts and tools for industrial production.

## Applications, products and services

Our ProVis 4.0 suite comprises both production control system components and integrated open-source solutions such as the FA³ST toolkit designed to meet the emerging combined requirements from Industrie 4.0, International Data Spaces (IDS) and GAIA-X technologies. We are driving forward the industry-mature development of open62541, our open-source implementation of OPC UA. We design PAISE®, the process model of AI systems engineering, and apply it to the systematic design and operation of AI-based complex and critical technical systems. Our environmental risk and crisis management systems are built upon WebGenesis® and the FROST® server, our implementation of the geospatial SensorThings API standard. With our Industrial Security Testing Framework ISuTest®, we offer IT security consulting and training, and perform vulnerability tests for networked automation components. We play an active role in standardization bodies such as the Standardization Council Industrie 4.0, the OPC Foundation, AutomationML e.V., Bitkom, VDI/VDE, DIN, IEC, IIC, and OGC.

## Infrastructure and lab facilities

With the Smart Factory Web, an IIC testbed, but also a reference implementation of a blueprint architecture of flexible production ecosystems and Manufacturing as a Service, we are advancing the concept of marketable solutions that use open standards to visualize production capabilities and assets in industrial manufacturing. We operate the Karlsruhe Research Factory on AI-integrated production, the AutomationML test center, a training laboratory for cyber security (LLCS), and lead the Competence Center Karlsruhe on AI Systems Engineering (CC-KING).

## Highlight topics

**KERES – Protecting Cultural Heritage from Extreme Climate Events**
Extreme weather events as a result of climate change are not only affecting nature.

*Charlottenhof, castle and park – one of the KERES research areas.*

Historical buildings, collection, and historical parks and gardens can also be affected by extreme weather conditions. Assessing the magnitude of this risk is an interdisciplinary task that requires the collaboration of historians, meteorologists, preservationists, restorers, and engineers. However, this discussion is currently rarely taking place in Germany, either on a scientific or societal level. The BMBF-funded KERES project aims at changing this and researches, with a focus on Germany, which risks arise from extreme weather events that are increasing both in frequency and extent, and which adaptation strategies should be developed.

In close cooperation with the relevant players and potential users, such as the Stiftung Preussische Schlösser und Gärten (Prussian Palaces and Gardens Foundation), Fraunhofer IOSB is building a knowledge platform that shows the current and future condition of a property (buildings and parks). The aim is to create as high a level of user orientation as possible so that the knowledge platform can be used sustainably over the long term. The platform is supported by an app, which will be developed during the project and can be used in both emergency management and prevention. The necessary data for the knowledge platform is being contributed by the Climate Service Center Germany (HZG-GERICS) and the Fraunhofer Institutes IBP and IMW.

**Open source software as a successful model**

For over 40 years, our department has been developing innovative software for use in a range of different fields. Many fashions have come and gone in that time, but there is a clear trend toward open source software (OSS). The OSS model creates an innovative, open and collaborative software development environment. This is especially important when working with standardization bodies, as in the case of our FROST® reference implementations for the OGC SensorThings API standard and open62541, our OPC UA implementation of the IEC 62541 standard.

The benefits of OSS are also clearly visible in European research projects such as OpenIoT and SymbIoTe and the work being done on IVCT software in NATO working groups: It is giving rise to a culture of collaboration that improves both the quality of the software and how it is distributed. This is leading to new business models beyond just the sale of proprietary software.

**Automated vulnerability detection for industrial IT components**

Networked machines and equipment are becoming increasingly common in the manufacturing industry. This is creating major opportunities to improve processes, but also poses new risks as industrial automation components become more vulnerable to attacks over the network. This is why we have developed the industrial security testing framework ISuTest®, a tool for finding vulnerabilities in automation components.

ISuTest® is designed to be an open, expandable framework, setting it apart from commercial competitors that use closed source software. The system helps manufacturers of automation components and provides support for establishing and performing vulnerability tests as well as for isolating vulnerabilities and correcting faults on the developer's side. ISuTest® has already been used to detect many vulnerabilities that have subsequently been confirmed by the manufacturer.

ISuTest® opens up the domain of security testing for automation experts, allowing the vision of "security by design" to be put into practice.


*ISuTest® consists of a distributed software framework and makes use of different hardware components. The hardware components are used for the automated execution of vulnerability tests, taking into account any input and output of the automation components to be tested.*

# IAS | Interoperability and Assistance Systems

**The Interoperability and Assistance Systems department researches and develops solutions that support people in interacting with complex information systems. In a "system of systems" approach, interoperability is vital.**

IAS

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**Research groups**

System architectures
Command and control systems
Knowledge models
Distributed systems
Networked information management

**iosb.fraunhofer.de/IAS**

## Research areas and competences

Our R&D projects in the field of software architectures for computer-based assistance systems focus on dialog design and interoperability up to the semantic level. We contribute to the technical networking of systems and their content. Using multimodal and multimedia interaction technologies, we tailor dialogs to suit specific users and tasks, which facilitates collaboration. Our cooperative information systems, web services and intelligent software agents distribute information to personalized end-user devices on time and in the right granularity. Modern, technology-based learning environments support users with reaching the expertise and the decision-making abilities they need. Our competences include designing, implementing, and evaluating system solutions for interactive sensor data analysis; modeling knowledge and integrating it into hybrid AI-based systems to support networked information analysis; and modeling users, workflows and application domains. We also specialize in competence management in distributed systems and the deployment of groups of heterogeneous mobile sensor carriers and robots, respectively.

## Applications and products

We develop components supporting the collection and the analysis of heterogeneous data and information, components for interactive image exploitation, semantic (e.g., ontology-based) information models and services, network-enabled information management systems, and training and education systems. Our work is based on the understanding of the respective domains and processes to be supported. Compliance with relevant software quality standards is integral to our development activities. Many of our partners and clients belong to the defense and civil security sectors.

Products include CSD (Coalition Shared Data) components for interoperable information exchange, e.g., between NATO partners in the field of in Joint ISR (Intelligence, Surveillance and Reconnaissance); i2exrep (Interactive ISR Exploitation Report), an interactive software tool for the creation and processing of reports that comply with standardized reporting formats, also being able to integrate specialized term databases that may be generated and maintained with the data tree editor DBED; AMFIS, a generic, modular ground control station for coordinating stationary and mobile sensor carriers and sensor network nodes for reconnaissance and surveillance by air, land and water vehicles and for evaluating and fusing the sensor data and the derived information; and Lost Earth 2307, an adaptive serious game framework for training image interpreters and other specialists.

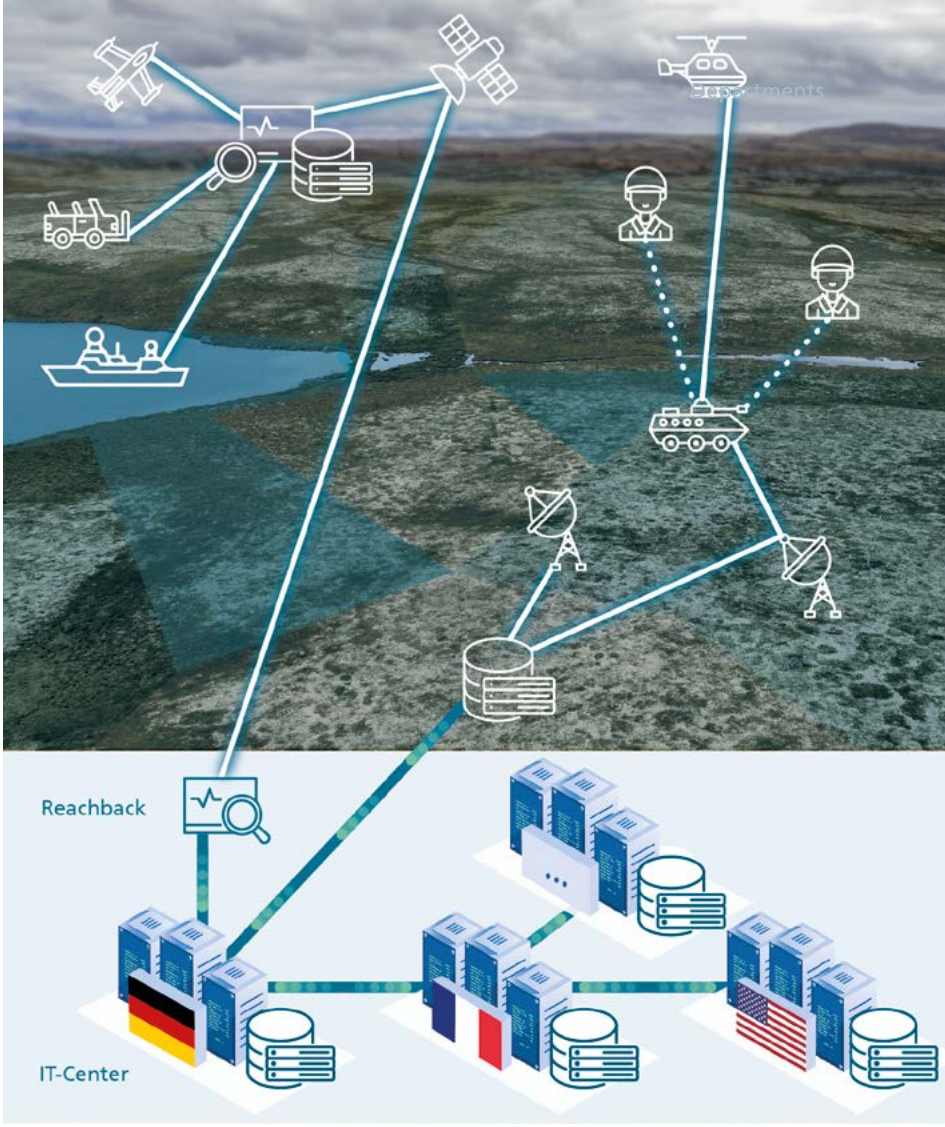
## Highlight topics

**Concepts, architectures and services for Joint Intelligence, Surveillance and Reconnaissance (Joint ISR; JISR)**

In ISR operations, remote exploitation and analysis, as well as multinational collaboration, are rather the rule than the exception, thus network-enabled data and information sharing is a major topic. To achieve this seamlessly, interoperability is key.

Actors and systems, processes and procedural instructions must be appropriately analyzed, modeled and coordinated to enable consistent, reliable, timely and secure exchange of data and information. Legacy systems need to be connected in an overall architecture. These aspects influence which technological concepts, patterns and solutions are applicable and selected. Artificial intelligence (AI) can support the human decision-maker if the appropriate algorithms are chosen, and sufficient information models can be created.

We are adressing these topics since many years, resulting in various contributions to interoperability standards, test procedures and systems (e.g., at the JISR Testcenter at WTD 81), as well as to systems and services for projects like VJTF 2023. For STANAG 4559 AEDP-17 compliant data exchange, storage, and retrieval architectural concepts are developed, and the Fraunhofer IOSB CSD PLUS Server and clients are integrated into complex systems of systems also connecting different security domains. Our research here addresses new concepts, architectures and solutions for data and information sharing in complex environments, as well as data and information analysis by AI concepts and tools.

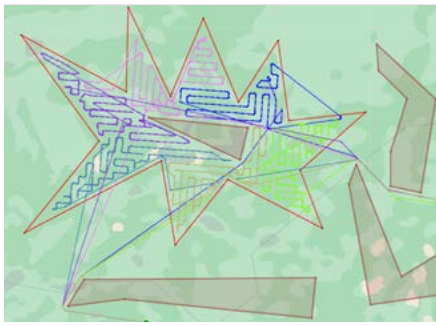



*Data and information dissemination in multinational operations.*

**Intelligent mission planning for heterogeneous groups of mobile autonomous systems**

To use heterogeneous groups of mobile autonomous systems effectively and efficiently for reconnaissance, the mission has to be "understood" by the group, and the corresponding tasks have to be analyzed to select the most suitable resources (sensors, actuators, and mobile carriers, etc.). Next up, the mission in itself has to be planned out. To enable the complete and resource-efficient reconnaissance of an area, the relevant parameters of the individual systems, such as detection ranges, sensor resolutions, speeds, power reserves, must also be considered at path planning.

We developed and implemented new algorithms for mission and path planning. Our PathPlanner software allows planning all trajectories that are necessary for performing reconnaissance by groups of mobile systems: approach from take-off to target position, trajectories for complete reconnaissance of complex areas and departure. Obstacles and prohibited areas with the necessary safety distances are taken into account during planning, as well as many parameters of the mobile systems, such as their turning radius or whether border crossings at the edges of the reconnaissance area are permitted. PathPlanner possesses a GUI, but it can also work as middleware and transmit path planning tasks and planned trajectories via different interfaces including ROS, MQTT. The software can get adapted to specific customer requirements, e.g., by adding interfaces and data formats.



*Path planning for a photo flight with six UAVs (Unmanned Arial Vehicles) for reconnaissance of a complex area (boundary in red) including approach and departure in the presence of several prohibited zones or obstacles (brown).*

# MIT | Machine Intelligence

**The Machine Intelligence department researches and develops automation solutions based on artificial intelligence (AI) and machine learning, providing human-machine interfaces for operation, maintenance and management in the factories of the future.**

MIT

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**Research groups**

Machine learning
Big data platforms
Assistance systems

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## Research areas and competences

We develop industry-compatible solutions that help people manage and control the complex production environments of today and tomorrow. For this purpose, we collect, analyze, and utilize data relevant to production. In order to exploit this data, we build big-data platforms and interoperability frameworks based on open standards, such as OPC UA. Thanks to machine learning, we can predict how real processes will behave, optimize them, ensure system integrity, and also diagnose the operating status of plant machinery. Our research focuses on model-based design, optimization methods, and knowledge-based system diagnosis. In the field of human-machine interfaces, we develop assistance systems that provide support in job training, manual assembly, and maintenance. This includes research into user experience, usability, and information, and interaction design.

## Applications and products

The range of possible applications and markets for our products is virtually endless. From modern, networked production in the automotive industry to small workshops, from robot cells to handheld drills – sensor data can be gathered in all kinds of environments and then simulated in models, in order to streamline processes and generate useful knowledge. Our vision: reliable, standardized communication for Industrie 4.0 to integrate machine and plant data using a plug-and-monitor system, and to automate the interpretation of this data with models that deliver sound information. We have also worked with the German Mechanical Engineering Industry Association (VDMA) to develop an OPC UA manual for medium-sized companies.

## Infrastructure and lab facilities

SmartFactoryOWL at Lemgo, a joint initiative of Fraunhofer IOSB-INA and the University of Applied Sciences and Arts in East Westphalia-Lippe, forms the Machine Intelligence department's main research infrastructure. The systems in operation there deliver large amounts of production-relevant data and are used for developing and testing prototypes for new assistance systems and interfaces.

Our "KI-Reallabor" or AI Living Lab features cutting-edge facilities and capabilities. Funded by the federal ministry of economy, it is an open but protected collaboration space for people and technology. With as few regulations as possible, the potential and effects of AI can be researched in real production environments. In close cooperation between science and industry, we create structured data sets that allow for analyzing the potential of AI, for identifying suitable use-cases, applying AI algorithms and networking systems with one another. Thus, the AI Living Lab supports companies in using data profitably in the long term and strengthens the innovative, trustworthy and secure exchange of data in the industry.


*Intelligent object recognition is the first step of intelligent traffic lights.*

## Highlight topics

**CUNA: Next level production at SmartFactoryOWL**

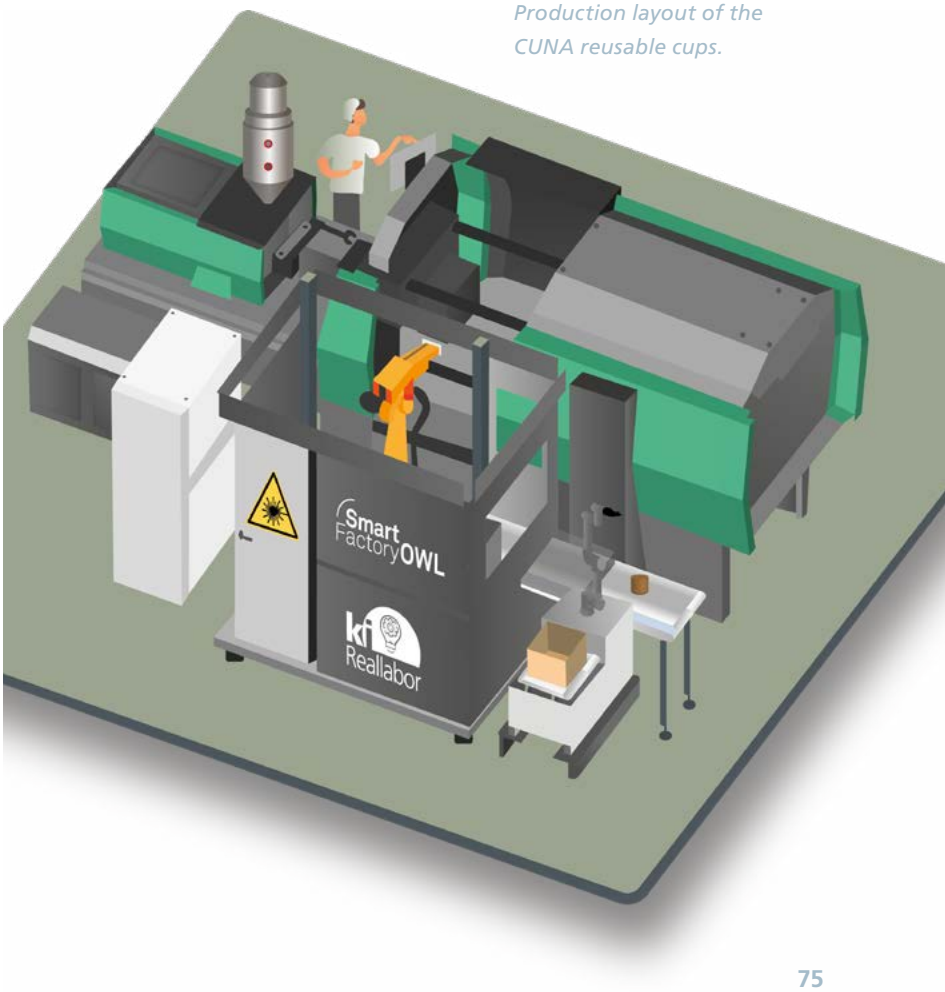
In summer 2021, Fraunhofer IOSB-INA and the startup CUNA Products GmbH started the real-scale production of cups ready for the market inside our research facility and with close accompaniment of our AI specialists. In total, a cooperation of ten partners who represent the whole value chain has formed around the AI Living Lab and the cup's production line, providing valuable insight into the ifs and hows of tomorrow's sustainable production processes. In particular, the product demonstrates how technical innovation and protection of the environment can harmonize. The cups are characterized by a sustainable concept with a future-proof product idea, as they are made from $CO_2$-neutral bio-based plastic that does not contain oil, and are both reusable and recyclable.

**AI and traffic lights: a worldwide novelty on the verge of breakthrough**

Artificial intelligence (AI), or more precisely "reinforcement learning", is an approach that has not yet been tested in the control of traffic lights in real road traffic. In Lemgo, our project "Artificial Intelligence for Traffic Signal Systems" (KI4LSA), aiming at intelligent, predictive traffic light control, is gaining momentum and has generated a great deal of public interest.

Together with the manufacturer of traffic technology Stührenberg and the Lemgo public utility company, we recently installed the technology at the first traffic light intersections. The goal is to improve traffic flow through adaptive, "learned" traffic light behavior, for example during rush hour. As the potential of this research project and our technology is considered high, a follow-up project addressing traffic lights for pedestrians already has been launched successfully.

*Production layout of the CUNA reusable cups.*



# MRD | Systems for Measurement, Control and Diagnosis

**The Systems for Measurement, Control, and Diagnosis department analyzes, models and optimizes technical processes in manufacturing, water, and energy infrastructures, robotics, automotive applications, and optical inspection.**

MRD

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**Research groups**

Process control and data analysis
Image-based measurement systems
Automotive
Multi-sensor systems

**iosb.fraunhofer.de/MRD**

## Research areas and competences

Our capabilities in modeling, simulation, and data analysis range from analytical, knowledge-based, and data-driven methods to the modeling, simulation, synthesis, and information fusion of sensor systems. They include block-oriented and finite element models as well as machine learning methods for classification, condition monitoring, and causality analysis. We specialize in developing autonomy algorithms for mobile robots – including construction machines – in unstructured environments and for self-driving cars. Our expertise in (real-time) image and signal processing includes generating and analyzing 3D data, visual navigation, and content-based image retrieval and evaluation.

## Applications, products and services

In process and manufacturing engineering, we develop tools that use machine learning to monitor, control, and optimize complex processes. In surface inspection, we research image-based techniques such as deflectometry, optical imaging measurement, and evaluation concepts, and automated microscopy. Our automotive focus is on developing a simulation platform for virtual test drives. We also use ground and aerial video analysis to build statistical models of road users' behavior, and design concepts and algorithms that pave the way for autonomous and cooperative driving.

We develop monitoring and optimization modules for water/wastewater and energy infrastructures. In robotics, we focus on techniques for localization and mapping, including environment-interactive path and trajectory planning, safe physical human-robot interaction, and controlling complex robotic kinematics. Applications for these technologies include service and inspection, logistics, security, precision farming, waste disposal, decontamination, and operations in hazardous environments.

## Infrastructure and lab facilities

We maintain a large test site for autonomous mobile robots that consists of both an outdoor area and a dedicated lab. Outdoors, we test how the robots perceive their environment and plan motion in unstructured spaces. In the ROBDEKON lab, our new, 250-square-meter lab building, we operate our indoor robots and build autonomous construction machines.

## Highlight topics

**dynOpt-En: an energy manager that activates energy sources according to supply and demand**

Achieving climate neutrality in real estate management requires a renewable supply of electricity, heating and cooling. The trend is moving toward cogeneration plants. Differences between supply and demand when it comes to energy from renewable sources mean there

*The autonomous excavator ALICE loads a transport vehicle.*

are times when too little or too much energy is being generated. Energy needs to be stored and the use of different energy sources needs to be dynamically optimized. When it comes to sector coupling between heat and electricity in particular, an intelligent balance of supply and demand is crucial.

The dynOpt-En project funded by the German Federal Ministry for Economic Affairs (BMWi) has developed an energy manager that optimizes cogeneration plants in buildings and accommodation in a holistic way. It is designed to store and use the power produced by the plant as locally as possible in the form of heat or electrical energy, while also adjusting heat pumps and peak load boilers to minimize ongoing emissions and costs. It does this by using a prediction algorithm: The dynOpt energy manager uses meter and sensor measurements in combination with weather forecasts to make continuous predictions. These predictions are used to match the different heating or cooling generators perfectly, including heat pumps and gas-fired boilers as well as cogeneration units, combined with photovoltaic or solar heat plants.

The energy manager has been designed as a fully online service, and therefore requires almost no on-site installation work. All the data is available through the data interface (web API), meaning that measurement service providers will be able to offer energy management as part of their service in the future. Useful figures relating to costs, energy consumption and $CO_2$ emissions are calculated and visualized in clear dashboard layouts [1]. The project has tested and demonstrated the functionality of the energy manager in three buildings, in which costs and carbon emissions were reduced by at least 15 percent.

**Autonomous construction machinery**

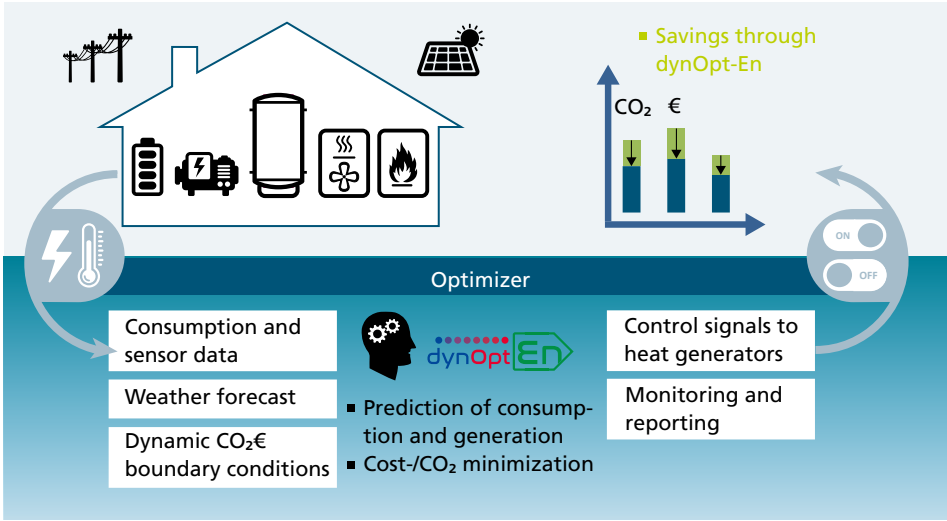
Remotely operated or autonomous robot systems can be used in harmful environments to make people's work safer and easier. In the field of landfill and contaminated site decontamination, we are currently conducting research into an autonomous excavator that removes contaminated layers of soil on its own.

To achieve this, a conventional excavator has been fitted with a large number of sensors to enable it to precisely identify its surroundings: With laser scanners and cameras, the excavator is able to produce a three-dimensional model of its environment. It can use this 3D model to find its own way to the operation site and avoid collisions, for example with other construction machinery. This also forms the basis for planning the excavation strategy and the specific movements of the excavator arm. Angular rate and acceleration sensors and GPS allow the excavator to orient itself precisely in its environment at all times.

The excavator's autonomy function is implemented using the "algorithm toolbox for autonomous mobile robot systems" developed at Fraunhofer IOSB, which integrates components for application-specific autonomy functions according to the principle of modularity.

**[1] Links to dashboards for real buildings:**

https://www.dynopt.de/servlet/is/107489/




*The dynOpt-En energy manager activates different energy sources in large buildings based on supply and demand to minimize costs and $CO_2$ emissions.*

# UWR | Underwater Robotics

**The Underwater Robotics department conducts research on remotely controlled and (semi-) autonomous underwater vehicles and develops control systems and hardware components. Modeling, simulation and decision-making support for complex water systems are other focal points of its research work.**

## Research areas and competences

We develop comprehensive, seaworthy systems and components for exploration, inspection and manipulation operations in the underwater environment. Underwater vehicles are a cross-sectional technology, with growing importance for the sustainable use of our oceans in many different respects: offshore wind energy, marine aquaculture, marine research and the removal of old munitions and microplastics from the oceans. Our research focuses on autonomy functions for underwater vehicles and AI-based sensor data analysis.

In the field of water systems engineering, we address the entire cycle starting from drinking water production, treatment and distribution right through to wastewater reuse. We model and simulate surface water systems and develop decision-making support systems and optimal control strategies based on these models. We address the energy-water-food nexus in our research work on modeling for aquaponics systems. In the context of the challenges posed by climate change, we also conduct research on warning systems for flash floods, which have already been tested successfully in a practical setting in Thuringia as part of the "STUWASYS" project, and on improving the resilience of water supply systems.

## Applications and products

We develop control algorithms for underwater vehicles and underwater robots for the purposes of exploration, inspection and manipulation of underwater infrastructures. As part of the interdisciplinary Fraunhofer research group Smart Ocean Technologies (SOT) in Rostock, we are working on the development of an underwater vehicle that will allow various maintenance tasks to be carried out underwater even without divers. In the "MISO-Inspector" project, we are creating a flexible sensor platform for inspection and analysis operations above and below water with a view to maintaining offshore installations. Our R&D activities relating to an autonomous underwater rescue robot, which we plan to use in swimming pools and lakes in the future, have attracted a great deal of media interest.

In the field of water management, for example, we are involved in the "Fraunhofer Innovation Platform for the Water-Energy-Food Nexus at Stellenbosch University" (FIP-WEF@SU) and in the "Nitrate Monitoring 4.0" project (see p. 48), which combines AI techniques with methods from environmental informatics and specifically the water domain in order to predict nitrate contamination in groundwater in terms of time and spatial distribution, and to contribute to a sustainable reduction.

## Infrastructure and lab facilities

We have a 12x8x3 meter research tank and a 1200 bar pressure testing facility for testing our maritime systems and components. Our diving drones and surface vehicles are also available for client-specific projects:

UWR

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**Research groups**

Underwater vehicles

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- TORTUGA ROV: The TORTUGA ROV family is a multifunctional family of agile, remotely operated underwater vehicles with diving depths of up to 500 meters. They can handle a wide range of tasks thanks to their flexible design and various interface options. Multiple sensors are available for underwater navigation and environmental sensing.
- DEDAVE 2000: This is an autonomous underwater vehicle with a diving depth of up to 2000 meters and a large payload range with versatile sensor equipment.
- C-CAT: C-CAT is a remotely controllable or autonomously operating catamaran with a payload of up to 300 kg and versatile sensor equipment.

## Highlight topics

**Underwater archeology**

In the field of underwater archeology, we have been cooperating successfully with the Saxony-Anhalt State Office for the Preservation of Monuments and Archeology (LDA) for many years now. At the end of 2018, we were successful in surveying and 3D modeling an approx. 7000-year-old submerged burial mound in the "Süßer See" lake in Saxony-Anhalt using an autonomous surface vehicle.

Since then, our TORTUGA ROV (remotely operated vehicle) has been deployed several times in the Süßer See and Arendsee lakes to investigate objects identified by surface sonar in greater detail. To do this, the ROV produces high-resolution video and sonar data of objects and structures that may elude even experienced recreational divers in the murky waters. In 2020, an underwater laser scanner from the company Kraken Robotik was integrated into the vehicle. This sensor facilitates the most accurate measurement of underwater structures to date – the discrepancies in the 3D model produced amount to less than one millimeter. This sensor underwent its first practical tests in the IOSB-AST test tank and later in both the Süßer See and Arendsee lakes.

**DEDAVE 2000**

The autonomous underwater vehicle DEDAVE 2000 is the "little brother" of DEDAVE. It was sold to the Canadian company Kraken Robotics in 2017 and has since been used primarily in the North Atlantic. DEDAVE 2000 is identical in structure except for some hardware component optimizations. The buoyancy foam used in the vehicle allows it to operate at depths of up to 2000 meters. In addition to the multibeam echosounder that is already installed, it will also be possible to equip the large payload bay with a state-of-the-art synthetic aperture sonar in the future, which – in addition to creating 3D profiles of the seabed – will also enable high-resolution images to be taken.

In August 2021, DEDAVE 2000 was able to show what it can do at the Baltic Live Trials of the European OCEAN2020 project (see p. 44). The task was to map a 30-hectare area of the Baltic Sea in southern Sweden.

*ROV belonging to UWR with integrated SeaVision laser scanner shortly before it was deployed in the Arendsee lake (November 2020).*

*Above: AUV DEDAVE on board the research vessel PLANET during the Baltic Live Trials (August 2021).*

# IAD | Interactive Analysis and Diagnosis

**The Interactive Analysis and Diagnosis department develops smart and innovative AI-based assistance systems for human-machine interaction. Privacy by Design ensures the responsible handling of personal data.**

IAD

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**Research groups**

Decision support systems
Perceptual user interfaces
Interactive systems
Explainable AI

**iosb.fraunhofer.de/IAD**

## Research areas and competences

Our research focuses on the optimization of human-machine collaboration. We develop methods of artificial intelligence (AI) to assist users in a situation-adaptive way. Our systems analyze large amounts of data in real-time and we address the entire chain from safe and secure data storage to the explainability and trustworthiness of AI methods. To support an intuitive human-machine interaction, we build secure, trustworthy, and GDPR-compliant camera-based AI components that detect and track users, classify their activities and support natural interaction modalities, such as gestures and speech. We explore human-machine interaction even in difficult work environments and provide solutions spanning from recognizing user needs to innovative assistance even in virtual and augmented reality.

## Applications and products

Our systems and competencies are used in a wide variety of contexts. Our AI-based assistance systems support medical experts in treatment processes and security guards in surveillance tasks, e.g. in monitoring maritime areas. Our camera-based perception components enable autonomous vehicles to understand the occupants' and driver's activities, e.g., to hand over the driving task to the driver during an automatic driving process if necessary, and to support the cooperation between humans and robots. Our Digital Map Table, a system for visualizing situations and planning tasks, is a long-term, ongoing project. It includes a virtual reality version that allows experts to collaborate on crisis scenarios without being present in the same physical location. We use Privacy by Design to offer solutions with high regard to privacy.

## Infrastructure and lab facilities

To develop and evaluate methods for driver and passenger assistance, we run a driving simulator with a fully networked Audi A3, a polygonal 180° screen, a display rearview mirror, and the freely configurable and scriptable SILAB simulation software from the Würzburg Institute of Transportation Sciences (WIVW).

We operate a laboratory where we analyze human activities and test new ways of collaboration between humans, robots, and other technical components (e.g. tools) in the production area.

Our Digital Map Table is available for demonstrating and evaluating new forms of human-computer interaction to support situation analysis and planning tasks. We run it on various devices – from tablets to desktop PCs to VR glasses.

## Highlight topics

**Explainable and Trustworthy AI**
Artificial intelligence (AI) has been playing a decisive role in shaping the economy and

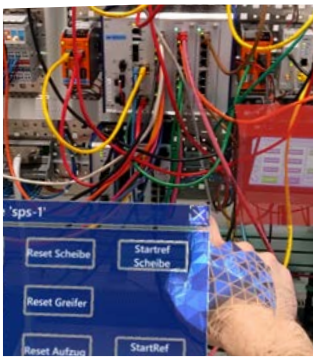

society in recent years. AI models can only develop their full potential if the AI is developed to high-quality standards and therefore can be fully trusted. Our XAI toolbox is designed to make AI black box models more transparent. The toolbox can be used for data analysis, debugging and the explanation of AI models and predictions. It generates two kinds of explanations: local explanations for a single instance and global explanations for multiple instances or the entire model. This improves the user's ability to debug and explain the results and in addition strengthens the user's trust in the AI methods in decision-critical sectors such as medical, automotive, maritime, etc.

We research explanatory interfaces in the context of AI methods and use design processes to tailor them to different user groups. Explaining outputs of AI models is also relevant from a legal point of view. The General Data Protection Regulation sets requirements in terms of transparency for data subjects once their personal data is processed, and the draft for a European Artificial Intelligence Regulation imposes a duty of supervision for users of specific categories of AI applications. In the latter case, manufacturers of AI-based solutions are directly made accountable for providing explainable systems.

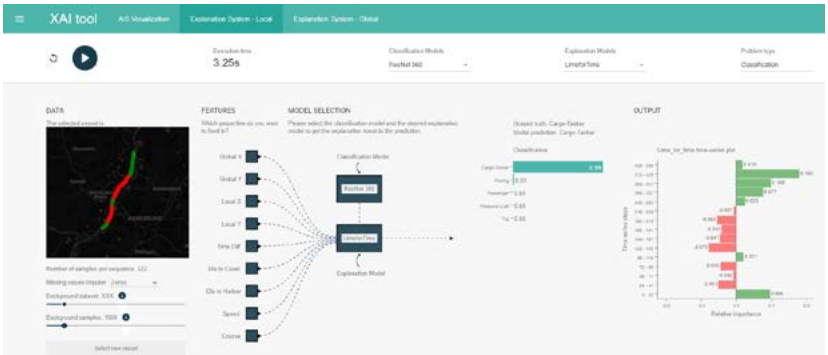
**Mixed Reality for Geointelligence and Quality Control**

Virtual and Augmented Reality have made great leaps forward in terms of available technology, such as markerless localization and high-resolution head-mounted displays. The Digital Map Table (DigLT) is a system that uses virtual reality to bring multiple users into a virtual, three-dimensional environment in which real-world geographic data from all over the globe can be displayed and interacted with. The three-dimensional display gives a much better insight into a scenario than two-dimensional maps and in addition to the display of data at a virtual table, allows users to „jump into" the map and stand on the top of buildings to get a better understanding of the real world.

In contrast, we use AR for displaying overlay information in manufacturing and quality inspection use cases. Hands are recognized and tracked, and use case-depending user interfaces are presented, guiding through individual tasks. Most use cases require 3D CAD models of respected components that are to be highlighted, e.g. to overlay their digital representations at their exact locations along with additional information. The open standard OPC UA is being used, which allows to submit all required data via WIFI.




*Above: The Digital Map Table in virtual reality.*
*Below: Augmented Reality for manufacturing.*




*XAI Toolbox in the maritime sector, adapted to explain ship trajectories' classifications.*

# OBJ | Object Recognition

**The Object Recognition department develops and evaluates algorithms designed to detect objects automatically and track them in sensor networks.**

OBJ

**Head of department**

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**Research groups**

Object recognition in sensor networks
Trackers and tracker assessment
Heterogeneous hardware structures
Video content analysis
Object recognition in 3D sensory data

**iosb.fraunhofer.de/OBJ**

## Research areas and competences

We evaluate video streams in the infrared and visual spectral bands and analyze laser sensor data. We use data provided by multiple sensors to describe three-dimensional, dynamic environments, and to trigger an automatic alert when specific incidents occur. Our research areas include aspect-independent descriptions of objects, registering images generated by mobile sensors with 3D context data, 3D data analysis including change detection, and semantic video analysis, i.e. extracting information associated with conceptual background knowledge in order to draw conclusions. Our expertise also includes work with heterogeneous hardware structures and the specification of suitable computing environments for complex real-time vision systems, as well as performance evaluation and risk assessment of tracking algorithms.

## Applications and products

A good deal of our work benefits Germany's armed forces, which employ our capabilities in defense-related projects. Our products help them gain a clearer awareness of any given situation, thus helping them to better carry out operations. One of our most recent innovations in this field is THS®, short for Target Handoff System.

## Infrastructure and lab facilities

Many scientific studies require a versatile research vehicle that lets them test and analyze a wide range of sensors and various operating scenarios. Mobile Distributed Situation Awareness, or MODISSA, is IOSB's experimental platform for hardware evaluation and software development on wheels. It is a valuable asset in automotive safety, security, and military contexts.

## Highlight topic

**Image-based navigation for helicopters**
For the German Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw) and together with an industry partner, we realized a technology demonstrator for image-based self-localization and navigation equipped in a helicopter. In a field demonstration, it could be shown that our system can estimate the present position and orientation of the helicopter platform with high accuracy and in real-time, making it an alternative or surrogate for GNSS-based positioning systems (global navigation satellite systems).

Target Handoff System (THS) is a combination of image exploitation algorithms that estimate the movement of a sensor during imagery acquisition and which are capable of registering the collected imagery against geo-data such as aerial imagery. Based on these algorithms, we could successfully participate in a joint research study for BAAINBw. Our


*A helicopter demonstration platform during starting procedure.*

objective was to deliver a complete system comprising sensors, optics, interface, and image exploitation hard- and software to be mounted to a helicopter platform and which would be able to estimate the helicopter's pose – position and orientation – during flight. This information should be passed on to the helicopter's aviation system via aviation certified hardware. The overall goal was to provide the position and orientation of the helicopter in GPS-denied situations, i.e., solely based on imagery. The desired functionality could be demonstrated in several test flights during which GPS was disconnected or actively jammed and spoofed.

The system we implemented collects imagery with the purpose of geo-localizing this imagery. For every geo-localized image the pose of the sensor is known in a global coordinate system (e.g., UTM). Geo-localization of an image is based on recognizing certain visual landmarks both visible in the geo-data and the present image.

Unfortunately, not every image from a sensor stream can be registered against geo-data in this way. To overcome this challenge, THS combines the sporadic geo-localization with estimates for the relative sensor movement on a frame-by-frame basis. This process is called visual simultaneous localization and mapping (VSLAM) and enables THS to provide the geo-pose for every single image.

Concerning geo-data necessary for THS, this data can look very different in different applications. Due to the VSLAM component, THS creates its own maps while working. These maps can be used as a reference in scenarios where an area is visited several times. Common geo data products such as orthophotos together with elevation models can provide the necessary information in other, more general scenarios.

In the present realization, THS can provide position information for a sensor or sensor carrying platform just as GNSS-based positioning systems. With its two components VSLAM and geo-localization, THS resembles the functional combination of an inertial measurement unit and a GPS receiver.

We believe that THS is a valuable option for positioning systems in scenarios where GNSS is not available or might be not reliable. If the application of visual sensors is possible (viewing conditions, etc.), THS can provide GNSS-independent position information, which is the basis for navigation, blue force tracking, and target acquisition in military operations.

*The helicopter trajectory estimated solely from live imagery during flight.*

# SZA | Scene Analysis

**The Scene Analysis department's research aims to satisfy the need for rapid, geo-referenced interpretation in the fields of intelligence, surveillance and reconnaissance.**

SZA

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**Research groups**

Image interpretation
Geo intelligence
SAR image analysis

**iosb.fraunhofer.de/SZA**

## Research areas and competences

We develop methods that efficiently process and exploit data captured by airborne and spaceborne systems – including segmentation, classification, change detection and multi-sensor data fusion. Our focus is on pattern recognition for remote sensing, which relies heavily on intelligence, deep learning, and transfer learning. Our portfolio includes interpreting multi-sensor and hyperspectral image data, as well as reconstructing objects using 3D analysis. We work on automatic georeferencing for image content and exploiting sensor data for simulation systems. In addition to standard multi-sensor data, we use synthetic aperture radar (SAR), which has the benefit of being able to acquire data at any time of day and in any weather.

## Applications and products

Our airborne multi-sensor platform is designed to monitor land and maritime environments, e.g. detecting oil spills. It carries a hyperspectral sensor, a high-resolution RGB camera, and a LiDAR sensor. Our priority is sensor data fusion and online processing for time-critical tasks such as monitoring pipelines and detecting camouflaged objects.

The CohRaS® (Coherent Raytracing-based SAR) simulator generates training data for classification based on deep learning. It comes with a toolbox that helps human analysts evaluate and visualize SAR data.

Using mobile sensors to explore a 3D environment calls for 3D sensor localization to enable navigation and mapping. The 3D environments captured with this technology can be used to generate terrain models for simulation. We designed our MOPED (Multispectral and Optical Physics-based Emission Distributor) software for exactly this use case.

With our remote sensing competences, we are solving tasks in application fields like distant inspection and smart farming.

## Highlight topic

**Photogrammetric in-flight measurement of airfoil shapes**

The reduction of fuel consumption is one of the utmost concerns of the aviation industry. Less consumption of kerosene saves costs and reduces polluting emissions. In this situation, retrofits offer the opportunity to improve an aircraft's aerodynamics, i.e., reduce its friction drag.

A common technology used to optimize an aircraft's shape is flow simulation based on computational fluid dynamics. For realistic simulations, the aircraft's actual shape in midair is required, especially the shape of the lifted, deformed airfoils. While an aircraft's shape can be easily acquired on the ground, it is challenging in midair: The positioning of experimental measurement systems is limited to the cabin's interior, and active sensors such as laser scanners and rangefinders are

*Application of measuring marks on the wing of a Boeing 777-300ER in Zurich, 2021.*

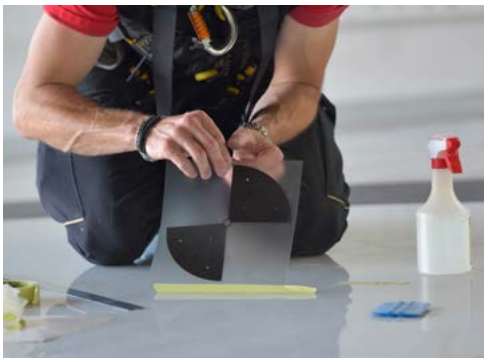
potentially dangerous since this implies the measurement through windows glass onto reflective surfaces.

To determine an airfoil's shape in midair, we developed a tailor-made solution for our partner and customer Lufthansa Technik AG. The developed measurement concept allows for the deployment of a single camera observing an aircraft's wing through a cabin window. This monocular approach paves the way to the easy application of a lightweight in-flight measurement system as a stand-alone solution during scheduled flights.

However, since a camera is a bearings-only sensor, a model describing the wings' deflections and additional measurements on the ground have to provide depth information. Measuring marks are stuck on the wing's upper surface, and their positions are determined using an electronic tachymeter. These marks are later observed in the images captured during the flight. The bending model assumes the preservation of arc lengths during the lift. Thermal expansions can be taken into account on a calculative basis. An optimization process provides the distances required for the polar point determination, and the computed 3D points are utilized to bend a virtual wing model supplied by a terrestrial laser scan. Eventually, the resulting model is used for flow simulations.

The selection of appropriate components is crucial for the design of the utilized photogrammetric system. An extended and constant depth of field, for instance, is required to obtain well-focused images. Furthermore, for the precise determination of optical paths, i.e., spatial directions, an in-situ calibration of the camera system is essential, also capturing the distortions caused by the window glasses.

In recent years, the feasibility and usability of the approach have been demonstrated during several transatlantic flights with long-range wide-body airliners. The results verified expected temporal changes due to the fuel consumption and the resulting loss of weight. The cost-efficient and unintrusive approach has been filed as a patent application [1]. In long-term work, such a monitoring system allows for conclusions about the mechanical load and thus the service limit of an airfoil.



*For a correct measurement, the application must be accurate to the centimeter.*

**1** Pfingsten, Kai-Christoph; Meidow, Jochen. Verfahren und Anordnung zur Vermessung von Flugzeugflügeln während des Fluges. Patent Application No. DE 10 2019 122 898.0

# VID | Video Exploitation Systems

**The Video Exploitation Systems department works on the automatic exploitation of signals from imaging sensors (mainly visual-optical and infrared) in complex, often non-cooperative scenarios.**

VID

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**Research groups**

Image-based reconnaissance and surveillance
Video system technology
Video-based security and assistance systems

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## Research areas and competences

Our research and development focuses on the exploitation of image and video data from moving platforms. Typical sensors in reconnaissance and surveillance operate as integrated components in either stationary, mobile land-based or spaceborne/drone (UAV) systems. We work on uses for sensor networks. Camera networks are increasingly found in critical infrastructure (e.g. railway stations, airports, industrial plants, military field camps), high crime areas in cities, and other places where they help to enhance situational awareness. Some of our products revolve around quality assurance in industrial production processes. Our main approaches comprise machine learning and other AI methods, model-based algorithms, estimation theory and aspects of data fusion.

## Applications and products

Some of the systems we have developed fulfill the highest industry and NATO standards for operational software products. Our ABUL (Automatic Image Exploitation for UAVs) system, for example, is in use by the German armed forces in their Castor field camp in Mali, Afghanistan and military facilities in Germany. Swiss facilities also use it for surveillance, reconnaissance, and border control.

Another development that is on its way to real-world implementation employs our NEST (Network Enabled Surveillance and Tracking) and the ivisX (Integrated Video Investigation Suite) systems. In Mannheim, we are debuting real-time intelligent video exploitation software for police operations, a first in Germany and indeed in Europe. The goal is to automatically detect physical assaults and to generate hints for a human decision-maker.

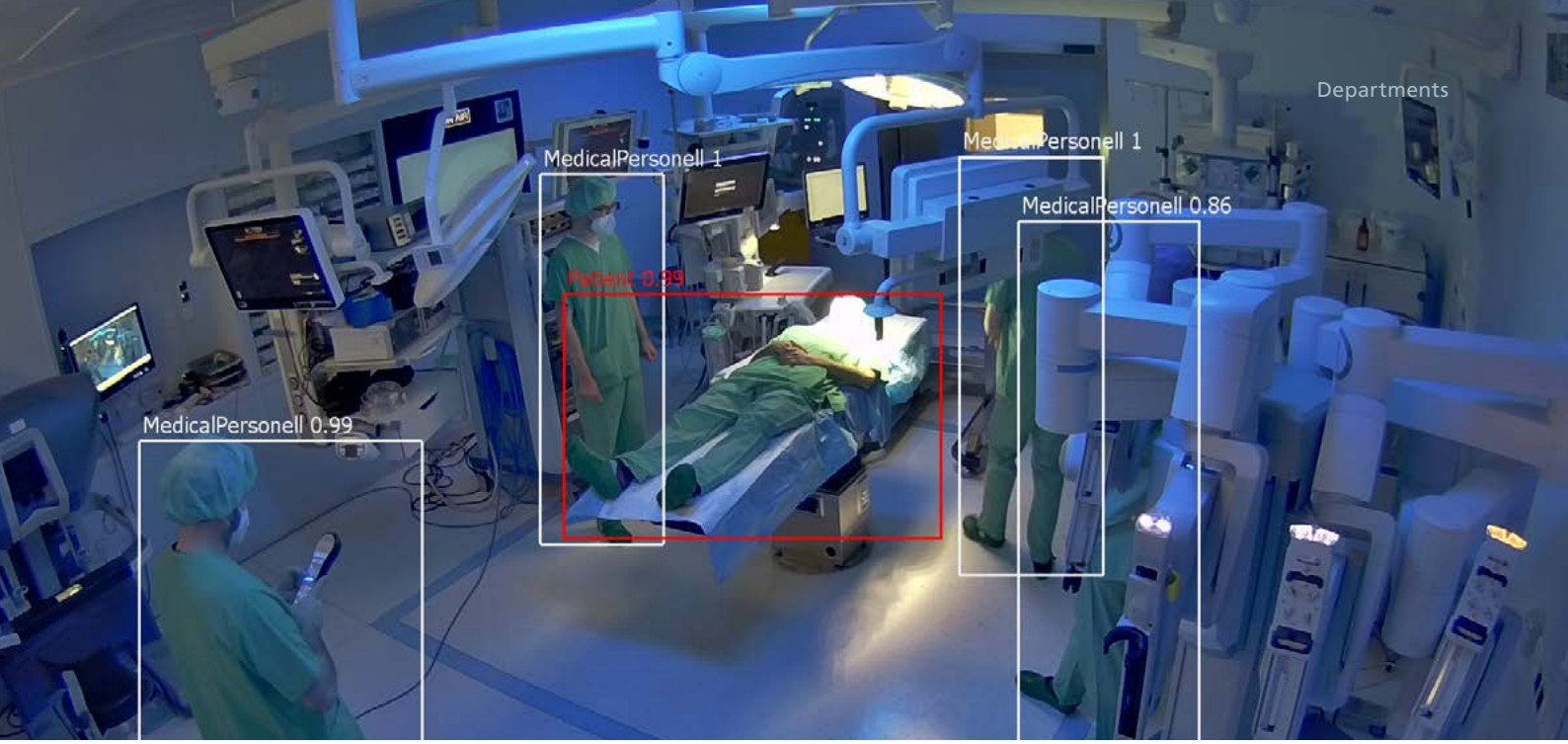
## Infrastructure and lab facilities

ABUL development, setup and test lab.

## Highlight topics

**Support of clinical processes by AI**
In cooperation with the Heidelberg University Hospital, we prototypically employ artificial intelligence (AI) to analyze video streams of "surveillance cameras" in operating rooms. The analysis is performed automatically and anonymously in a way that requires no interaction between the user and the AI and ensures that no user can observe the video streams.

One result of the AI-based video analysis is the automated determination of the operating rooms' usage periods. To accomplish this task, the AI anonymously recognizes the people in the field of view of the camera and estimates the number of persons located in the operating room. Afterwards, the information is transmitted to a higher-level information system of the Heidelberg University Hospital. Additionally, the AI is trained to distinguish




medical personnel, patients and cleaning personnel. The analysis is done by the AI in a two-stage approach with the first stage detecting all people and the second stage identifying the roles of the detected people.

A major challenge in the project was the small amount of available training data due to data protection. Thus, optimizations from the field of few-shot learning like strong data augmentation are applied. This synthetically increases the diversity of the images by showing the images multiple times to the AI with random variations in terms of color and image range. These approaches can ensure, and possibly enhance, data protection as well as increase the efficiency of the training process of the AI.

**Fast and resource-saving person detection**

Person detection has gained massive interest recently due to the COVID-19 pandemic and the requirement to enforce distancing regulations. However, the presence of permanently installed surveillance cameras is limited. Thus, cameras mounted on small UAVs (Unmanned Aerial Vehicles) are a perfect solution for verifying compliance with the regulations. To enable automatic processing of the verification on drones, we developed an AI-based person detection solution capable of running on low-power embedded devices in real-time.

To achieve real-time operation on the chosen Nvidia Jetson platform, we designed a custom convolutional neural network architecture that provides a low processing time while retaining high detection accuracy. Due to the application of an improved learning algorithm and careful hyper-parameter selection, we were able to further improve the accuracy without increasing the required runtime of the network.

Additionally, we converted our network to the TensorRT execution environment which is highly optimized for the processing units of the Jetson platform and is capable of utilizing a compact and fast 16-bit floating-point format as number representation.

In total, we can achieve real-time operation at about 20 frames per second with a very high detection accuracy and a small number of missed detections while only requiring 15 watts of power. Thus, our system can be easily deployed on drones or used for other mobile applications.

*An image of persons processed by our AI-based person detector with the detected persons being highlighted with bounding boxes.*

*Example results of the AI-based video exploitation. The bounding boxes visualize the persons detected by the AI and the texts above them show the recognized roles as well as the confidence. The confidence indicates how "reliably" the AI has assigned the roles, where 1 stands for the highest and 0 for the lowest confidence.*

# VBV | Variable Image Acquisition and Processing

**The Variable Image Acquisition and Processing group researches computational imaging and develops novel approaches and methods for artificial vision systems.**

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**About**

The VBV research group does not belong to any of the scientific departments; instead, it forms the institutional link between Fraunhofer IOSB and Karlsruhe Institute of Technology's Vision and Fusion Laboratory, the chair held by Fraunhofer IOSB head of institute Prof. Beyerer.

**iosb.fraunhofer.de/VBV**

## Research areas and competences

Artificial vision systems consist of an illumination source emitting light onto the scene, an image acquisition device capturing the reflected light, and image processing algorithms extracting relevant information out of the observed signal. Traditionally, these three components are optimized independently so that the scene is well illuminated, a sharp image is formed on the sensor, and the algorithms work fast and accurately.

We employ computational imaging methods which break with this tradition by jointly optimizing illumination, image acquisition, processing algorithms, and even scene parameters with respect to the vision task on hand. Depending on the application, this might involve a coded imaging pipeline where the intermediate image that is formed on the sensor is not interpretable for the naked human eye but, when adequately processed by the optimized algorithms, can yield results that are superior to those of a comparable traditional system.

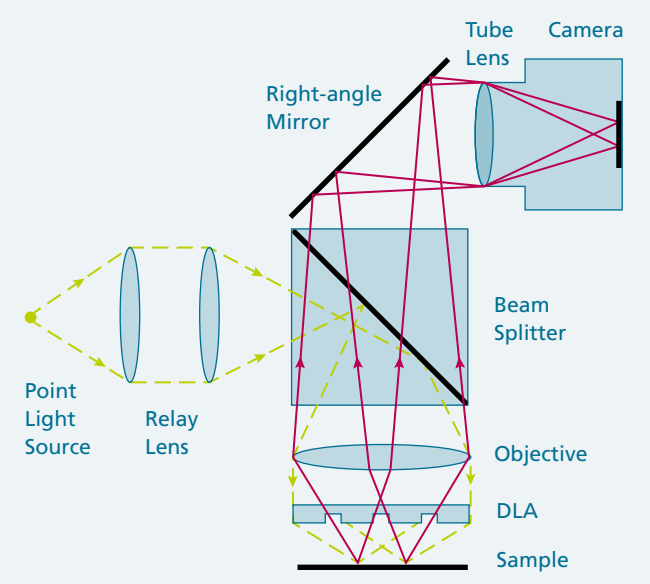
## Applications and products

Our research activities cover various artificial vision applications. Tackling challenging open questions in the field of automated visual inspection constitutes one of our core topics. For example, we orchestrate multiple light sources to acquire a set of images where the object under test is sequentially illuminated from multiple directions. Specially designed algorithms process these images to achieve maximum signal-to-noise ratio, i.e., an image, in which material defects are visualized with high contrast. Furthermore, we develop solutions for the inspection of partially or fully specular (i.e. mirroring) surfaces, transparent objects and thin films on curved surfaces, where conventional approaches typically cannot be applied.

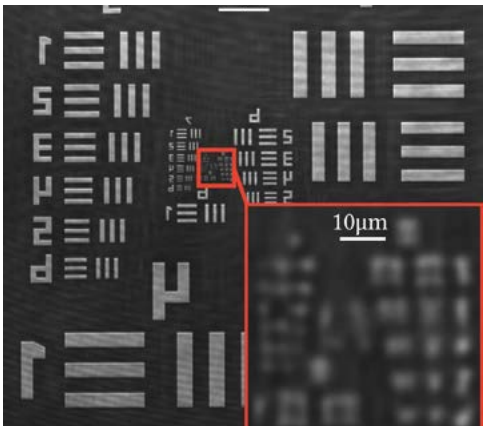
Our research results can also be applied to other domains, e.g., for detecting contaminants in food products via anomaly detection or for synthetically increasing the resolution of images acquired with a low-quality microscope lens.

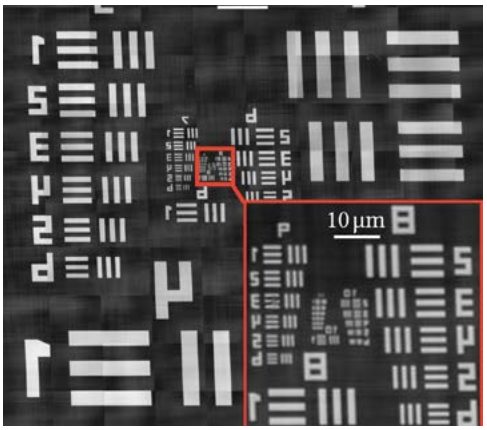
## Highlight topics

**High-resolution surface measurement by direct-imaging diffractive optical elements**
Traditional confocal microscopy setups all share the unavoidable tradeoff of either providing a high resolution or a large field of view. Increasing one leads to decreasing the other. We developed a diffractive lens array by employing specifically designed diffractive optical elements (so-called DoEs). Those DoEs produce an illumination spot array with high numerical aperture and allow to directly image through them. The resulting images have high resolutions in both lateral and axial directions.





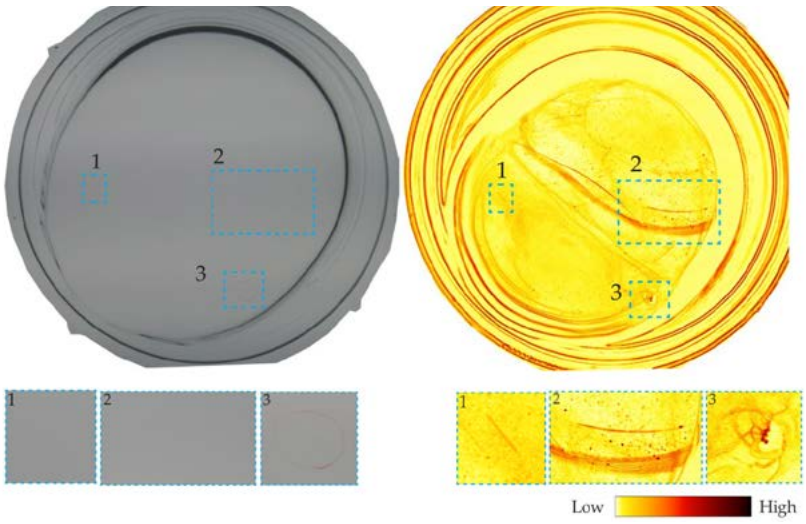



*Confocal microscopy with direct-imaging DoEs: the optical principle (top left); photo of a prototype (top right); resulting images of a test target with conventional microscopy (bottom left) and our proposed approach (bottom right).*

**4D light field acquisition and processing for the visual inspection of transparent objects**

Transparent objects can be affected by material defects that are hard to detect with conventional inspection methods since they are transparent themselves (enclosed air bubbles, scratches, etc.) and only influence the propagation direction of light. We developed a novel sensor device, a laser deflection scanner that can acquire four-dimensional light fields containing information about the light's direction of propagation. Through suitable processing algorithms, also challenging transparent material defects can be revealed with high contrast.




*Inspection images of a washing machine door glass: none of the material defects are made visible by a conventional bright field inspection approach (left); all defects are revealed and shown with high contrast by the novel laser deflection scanner and the light field processing methods (right).*

# Facts and figures

## 2020 – 21 in numbers

**>200**

committee memberships

Fraunhofer IOSB scientific staff are sought-after experts on boards and standardization bodies and in numerous expert groups.

**33**

trade fairs and exhibitions

We exhibited our technology at trade fairs such as SPS - smart production solutions, E-world energy & water and IAA Mobility as well as specialist conferences and theme days, including many events held purely online due to the coronavirus pandemic. We also attended six career shows.

**117**

teaching activities

such as lectures, seminars, tutorials and practical courses at different academic institutions were performed by our staff.

**2**

visiting scientists

worked with us for longer periods of time, starting from half a year.

**1**

spin-off

started taking technology developed at Fraunhofer IOSB and four other Fraunhofer Institutes to the market: the Data Competence Center for Cities and Regions (DKSR).

# >550

## journal and conference papers

have been authored or co-authored by Fraunhofer IOSB researchers.

# 21

## doctorates

Twenty-one researchers working at Fraunhofer IOSB passed their doctoral examinations in 2020 and 2021.

# ≈1,400

## participants

attended special events and conferences organized or co-organized by Fraunhofer IOSB and its scientific staff, when adding together on-site and virtual events.

# 50

## patents granted

Applications for a further 39 patents have been disclosed in 2020 and 2021. In addition, six product names were registered as trademarks.

**For all details on publications, academic teaching, lectures, technology transfer and outreach activities, please refer to the comprehensive online appendix to this annual report:**

www.iosb.fraunhofer.de/annual-report-2022

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IAD, MRD
Consultants: Univ.-Prof. Dr.-Ing. habil. Pu Li,
Prof. Dr.-Ing. Rainer Stiefelhagen

**Counter-improvised explosive device**
Chair: Dr. rer. nat. Ilja Kaufmann | OPT
Participating departments:
OBJ, OPT, SIG, SZA, VID
Consultant: Prof. Dr. Maurus Tacke

**End-to-end software development**
Chair: M. Sc. Philipp Hertweck | ILT
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**Event based vision**
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**Machine learning**
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Prof. Dr. rer. nat. Wolfgang Karl,
Prof. Dr.-Ing. Rainer Stiefelhagen

**Multispectral data acquisition and exploitation**
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Prof. Dr.-Ing. Uwe Sörgel

**Self-organization of complex systems**
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**Flexibilization of production systems for energy supply**
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**Autonomous systems**
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