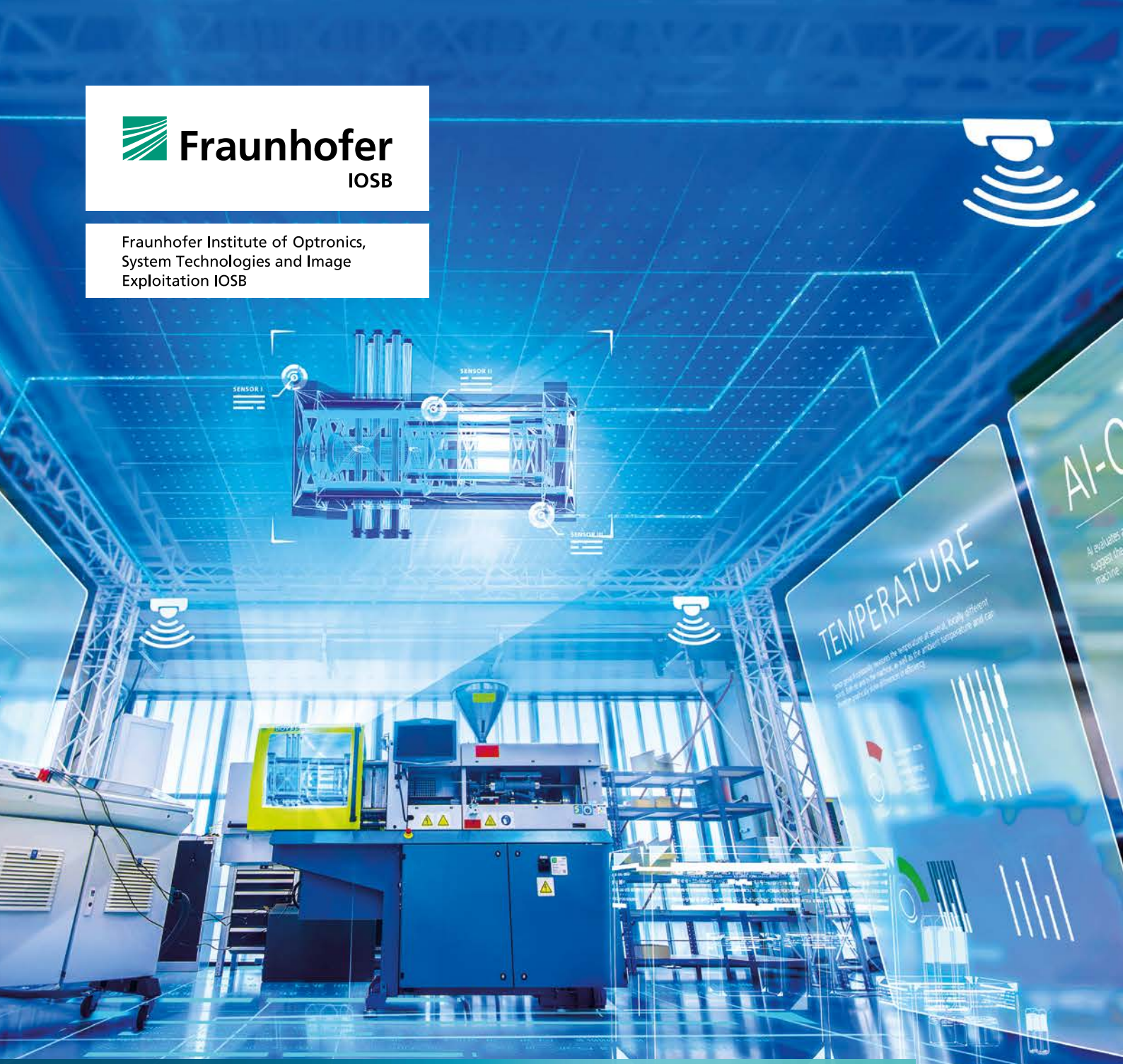
Fraunhofer IOSB

Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB



Progress report 2023/2024

Digital technologies for productivity, sustainability, and security

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The cover image shows a real-world experimental setup at the Karlsruhe Research Factory, designed to generate training data for machine learning in an industrial production environment. The photo serves as a backdrop for our artist's illustration of digital twins embedded in a comprehensive data space.

We help harness the full potential of digital technologies

Digital devices have become omnipresent in today's world, and few activities remain entirely analog. Yet, this high degree of things being digitized doesn't necessarily mean that digitalization, in a transformative sense, is happening. According to the Gartner Glossary, digitalization, as opposed to digitization, is "the use of digital technologies to change a business model and provide new revenue and value-producing opportunities." [1]

Digitalization is thus about fundamental change, about opening up new opportunities. However, beyond Gartner's definition, it should aim not only for economic advantage and increased revenue, but for value creation in a much broader sense. In line with this, our goal is to future-proof our society with the aid of digitalization. One focus is **productivity**, because it is key for our economic strength and prosperity. To meet today's needs, productivity has to go hand in hand with flexibility and resilience. It must be resource friendly and comply with environmental and social standards, which leads to the second focus: **sustainability**. Sustainability not only concerns industry and its supply chains, it also extends to the utilities sector, the energy transformation, and mobility. As we must acknowledge, while extreme weather events and armed conflicts are closing in on us, all the progress mentioned is pointless if security is lacking. Therefore, **security**, in a comprehensive sense, is a third focus.

To achieve these ambitious goals, digitalization, like technology in general, is not the sole solution, but it plays a pivotal role. At Fraunhofer IOSB, we leverage our technological expertise and in-depth knowledge of application domains to contribute to the solution.

Our research focuses on technologies that bridge the gap between the real and digital worlds. We use sensors to transform real-life situations into data and then analyze and exploit that data. We create digital twins of real-world entities and systems — whether it be machines, products, critical infrastructures, crowds, or even battlefields — and network stakeholders by helping to create interoperable, federative data spaces. We apply physical models and/or create data-driven models through machine learning, to push the boundaries of experiential knowledge through simulation. We integrate the insights gained into dashboards and situation pictures. We develop autonomously operating systems for appropriate applications. And we put the human in the loop wherever necessary, providing innovative interfaces for interaction and empowering them to make the best possible decisions.

That is what we can contribute to achieving the benefits outlined above. That is what this report is about.

1 www.gartner.com/en/glossary

Preface

Dear Reader,

Fraunhofer is currently focusing with renewed intensity on its core objective: the transfer of ideas into practice in order to strengthen Germany as a business and innovation hub. In particular, Fraunhofer sees itself as an innovation partner for SMEs, the cornerstone of the German economy. The success of this Fraunhofer mission is summarized — despite the lack of detail involved — in one key figure: RhoWi, the ratio of business earnings to operating budget. Our RhoWi of 33 % last year corresponds almost perfectly to the ideal specified in the Fraunhofer model of funding from three equally weighted pillars: industry projects, publicly funded projects, and base funding.

However, for us as an institute with a relevant share of funding allocated from the budget of the German Federal Ministry of Defense and an important pillar in defense research, another aspect is important in strengthening Germany: its security and resilience against all types of threats — military, technical, terrorist, natural, and criminal. This topic has become more prominent in the public consciousness since the "Zeitenwende", the turning point announced by German chancellor Olaf Scholz in the wake of the war against Ukraine.

This is not only reflected in the growing benevolent interest in defense research, for example on the part of the media. The idea of dual-use research, i.e. the use of synergies between the civilian and defense sectors, is also increasingly being discussed and seen as a sensible and efficient concept. For us, of course, this approach has long been common practice, and we hope that the discursive momentum will help us make tangible progress, including in the service of Germany's and Europe's technological sovereignty.

Real transfer, however, i.e., to actually transfer research results into productive use and not stop at the demonstrator and prototype stage, remains a challenging undertaking.

Prof. Dr.-Ing. habil. Jürgen Beyerer, head of institute of Fraunhofer IOSB

We are tackling this at various levels. Among other measures, we have refined our most important internal funding instrument, the Technology Development Program (TEP, see p. 15). And we discuss effective innovation paths for the German Armed Forces in the interview on p. 45. Of course, you will also find many other developments from the 2022/2023 reporting period in this issue: The Karlsruhe Research Factory, whose opening we reported on in the last issue, has been established and "brought to life," and the bridge professorship between Fraunhofer IOSB-INA and Bielefeld University on the subject of cognitive automation, which had been announced for some time, has been filled. And in many publicly and internally funded projects — which are naturally the focus of this report, since industrial collaborations are generally subject to non-disclosure agreements — we are helping to drive forward pioneering developments.

Transferring the state of the art in science into the state of the art in technology and bringing it into application: This mission remains demanding, and not just because of fundamental challenges. The cloudy economic outlook is making things even more difficult. However, even though R&D funds in many companies may be more limited than before, innovation remains the decisive lever for gaining a competitive edge and combatting the crisis.

Let's explore the best ideas and forms of cooperation together! We are your partner, please don't hesitate to contact us at any time.

Sincerely,

Jürgen Beyerer
Head of Fraunhofer IOSB

Contents

Highlights

1. Digital technologies for resource-friendly, future-proof production

Data space projects and Manufacturing-X
After years of Industrie 4.0 primarily advancing the internal networking of production facilities and creating opportunities for data-driven optimization, the potential of comprehensive, cross-site and cross-company data ecosystems has recently come into focus. Experts unanimously see great potential here for a future-oriented transformation of the economy, which should be aimed at sustainability, resilience in times of global crises, implementation of the circular economy and new, contemporary business models. In Germany and Europe, this includes the understanding that the emerging data ecosystems should be collaborative and federative. Trustworthy solutions need to rely on open standards instead of being manufacturer-specific and causing vendor lock-in. They should guarantee digital sovereignty: Those who share data are to retain control over who uses it, how, when and for what purpose. We at Fraunhofer IOSB were involved in realizing this vision at an early stage, particularly in the Industrial Data Spaces (IDS, now renamed International Data Spaces) and Gaia-X initiatives.

During the coronavirus crisis, economic stimulus policies created the opportunity to turn this vision into concrete reality through the end-to-end digitalization of supply chains in the automotive industry: The **Catena-X Automotive Network** received over 100 million euros in funding from the German Federal Ministry for Economic Affairs and Climate Action (BMWK). The lighthouse project, which will run until summer 2024, involves major OEMs, suppliers, important players in the IT sector and research institutes. At Fraunhofer IOSB, we have played a key role in shaping one of the pillars of Catena-X: We have introduced production-related topics into the project and are also actively engaged with them. This applies to three out of ten use cases, in particular "manufacturing as a service" (MaaS). The Smart Factory Web, which we have been developing for many years, plays a central role as an architectural blueprint here.

Blueprint study: Manufacturing-X data space:

www.iosb.fraunhofer.de/bauplanstudie

Subsequently, a follow-up idea gained momentum: to advance the digitalization of the manufacturing industry using a similar approach. This led to the **Manufacturing-X** initiative, a framework program to create interoperable data ecosystems for various industries, which the BMWK endowed with over 150 million euros. We have been involved in the project since the inception phase and have also co-authored the study "Bauplanstudie: Datenraum Manufacturing-X" ("Construction Plan Study: Manufacturing-X Data Space"), which was commissioned by the German Mechanical and Plant Engineering Association (VDMA) and the German Electro and Digital Industry Association (ZVEI).

Our particular focus within the manufacturing industry has always been on factory equipment suppliers. For this industry specifically, the BMWK funded the **Factory-X** project. Launched in 2024 and coordinated by Siemens and SAP, the project aims to create a data ecosystem. The additional challenge here is to generate added value through vertical networking in addition to horizontal data exchange along the supply chain. All branches of Fraunhofer IOSB participate in Factory-X. We help develop basic services relating to digital twins in accordance with the Industrie 4.0 standard (asset administration shell) and are contributing to the MaaS, circular economy, energy consumption and load management use cases. Our department Cognitive Industrial Systems (KIS) is even leading the modular production use case.

Furthermore, Fraunhofer IOSB is also involved in Manufacturing-X projects for other sectors, including **Process-X** for the process and chemical industries and **energy data-X** for the energy sector. We have also co-initiated a complementary transfer project, **Transfer-X**, which focuses entirely on using targeted information and training modules to help SMEs understand the benefits of participating in the emerging data spaces and to lower the threshold for joining.

With Manufacturing-X, German industry can transform itself internationally from a factory equipment supplier into a digital supplier and at the same time become a pioneer in climate-friendly industrial production.«

Dr. Robert Habeck,
Federal Minister for Economic Affairs and Climate Action

AI systems engineering and the "AI Alliance Baden-Württemberg"

To systematically and reliably bring artificial intelligence into productive use in the engineering domains: this is the objective of AI systems engineering is all about, a new discipline that Fraunhofer IOSB has helped launch in recent years and is driving forward in the field of industrial production in particular.

Fraunhofer IOSB contributes its AI and AI systems engineering expertise as a founding member of the AI Alliance Baden-Württemberg. This cooperation aims to create an internationally competitive AI ecosystem for Baden-Württemberg for a wide range of application domains, such as production, logistics, medicine, and smart cities. Six regions, including Karlsruhe, are pooling their expertise for this purpose. Fraunhofer IOSB is heading up two subprojects that were launched in 2023: The "data platform" subproject focuses on creating a low-threshold infrastructure for companies, especially SMEs, and the public sector to share AI assets, i.e., data sets and AI models. The intended basis for business is a private-public partnership model. Ethical and legal aspects such as the implementation of the EU AI Act and data sovereignty are given high priority. The second subproject, "AI Challenge," will organize a series of regional workshops that will ultimately incorporate the challenge of AI systems engineering into practice: Using the appropriate methodology, the aim is to harness AI in the product and service development of businesses and public authorities. The goal of the AI Challenge is thus to encourage innovative projects in accordance with the regional thematic priorities.

More on the topic: "Data spaces and digital twins" (visIT thematic brochure, in German)

https://services.iosb.fraunhofer.de/visIT/datenraeume

“SWAP-IT” — Modular production architecture
Traditional concepts in the manufacturing industry are reaching their limits due to volatile markets, rapidly changing product generations and increasing individualization requirements. To address this issue, Fraunhofer Institutes are working on an intelligent, adaptive production environment in the Fraunhofer lighthouse project named “Heterogeneous, workload-optimized robot teams and production architectures (SWAP)”. As part of this project, Fraunhofer IOSB has been co-leading the development of the new “SWAP-IT” production architecture, which is being validated on the basis of use cases from various industries. It replaces inflexible, static processes and modularizes production from end to end. A newly developed production control system based on the “Production Flow Description Language” allows to specify jobs that machines or robots execute autonomously. Which machine will perform which process step is not decided until runtime — depending on system status, time constraints, and other factors. Manual work steps can also be integrated into the process. The OPC UA protocol enables vendor-independent interaction between the machines and the process control system.

Project page with explanatory video on SWAP-IT:

www.iosb.fraunhofer.de/swap

Research unit and Collaborative Research Center funded by the DFG
Exploiting the full potential of AI for industrial production: That is the vision of the Karlsruhe Research Factory for AI-integrated Production, opened in 2022, which we operate together with the Fraunhofer Institute for Chemical Technology ICT and the Karlsruhe Institute of Technology. Receiving two funding measures from the German Research Foundation (DFG) in this context is a strategic success for the further development of scientific activities at the research factory.

The DFG AI Research Unit 5339 “AI-based Methodology for the Fast Maturation of Immature Manufacturing Processes” will help to further integrate the research fields of artificial intelligence and production engineering to advance the rapid industrialization of manufacturing processes. Funding is provided for eight principal investigators, including Prof. Jürgen Beyerer, who is also the research unit’s spokesperson, and Dr. Julius Pfrommer, department head at Fraunhofer IOSB.

The new DFG Collaborative Research Center (CRC) 1574, “Circular Factory for the Perpetual Product,” pursues the vision of facilitating integrated linear and circular production on an industrial scale with the aim of transferring parts from used products into current product generations with minimal use of resources and a high degree of automation. Prof. Beyerer and Dr. Pfrommer are principal investigators for this CRC, too.

"Waste4Future" — closing the plastics cycle

In the Fraunhofer lighthouse project "Waste4Future," a network of eight institutes is finding new ways to significantly increase the material recycling of plastics. To this end, a holistic, entropy-based evaluation model is being developed that transforms the previously process-led recycling chain into a material-oriented one: Sorting technology that combines sensor technologies such as hyperspectral imaging, radar and active thermography recognizes which plastic fractions are contained in the waste. Digital twins of materials and systems are then used to determine the optimal recycling path. The goals are economic efficiency, high purity levels in plastics sorting and robust material characterization, which also includes black plastics and previously neglected criteria such as the degree of aging.

At Fraunhofer IOSB, we are applying our expertise in the field of optical and hyperspectral sensors as well as various classification approaches based on decades of experience in bulk material sorting. We are also building a demonstrator for the advanced characterization and sorting of plastic streams based on AI-supported data analysis. At the same time, we are contributing our expertise in digital twins and the FA³ST service. FA³ST stands for "Fraunhofer Advanced Asset Administration Shell Tools," an open source software suite that Fraunhofer IOSB has been developing in other projects. FA³ST makes it easy to implement standard-compliant digital twins based on the advanced asset shell (AAS) specification maintained by the International Digital Twin Association (IDTA).

2. Digital technologies for security and safety

Digital situational picture for networked crisis management

In the event of a crisis or disaster, quick action and good decisions are essential. The smooth and efficient exchange of information and data between ministries and responsible authorities at various administrative levels is crucial in this respect. Together with the Baden-Württemberg Ministry of the Interior, Fraunhofer IOSB has developed the "Electronic Situation Dashboard for Civil Protection" (ELD-BS), a digital tool that meets these requirements and thus decisively supports effective staff work and crisis management. The planning and operation support tool has been used extensively in Baden-Württemberg for years in the context of exercise scenarios and real-life situations — from the state level down to the regional councils and the disaster control authorities at the municipal level. At the same time, new functionalities are constantly being added.

The ELD-BS is based on WebGenesis®, Fraunhofer IOSB's own framework for web-based information systems. Its functions include a wide range of visualization options for displaying the situation, target group-oriented processing of messages and information, automated information exchange with the radiological situation centers, a GIS-based crisis object database, a tool for central evacuation and accommodation management and a document sharing portal which can be used throughout. The ELD-BS has demonstrated its worth, including in the management of the coronavirus crisis and during a major evacuation operation in Freiburg in early 2023. Not only did thousands of citizens have to temporarily leave their homes, but around 200 patients from the university hospital also had to be relocated after an aircraft bomb from World War II was found.

Greater public safety and security through simulation of urban infrastructure

In 2022, the Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS went into operation in Berlin. In SIRIOS, the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, Fraunhofer-Institute for Open Communication Systems FOKUS, Fraunhofer Institute for Transportation and Infrastructure Systems IVI, and Fraunhofer IOSB pool their expertise with the aim of creating a technology and innovation platform for public safety. Staff from the four institutes are working together and in close collaboration with security organizations to build a research, testing and training environment.

Regardless of whether it's a medical crisis, an animal epidemic or a gas shortage — a standardized digital tool for modern and comprehensive staff work is at our disposal. This will significantly strengthen the state's security architecture.«

Thomas Strobl,
Minister of the Interior in Baden-Württemberg

In early April 2024, SIRIOS and the state of Berlin signed a cooperation agreement: New technologies will be developed, tested, and applied in close collaboration — for security situations specifically tailored to the German capital. Specifically, the plan is to hold regular joint workshops and conferences, share research-relevant data, and scientifically assess operational situations.

Two scenarios form the starting point for the scientific research and activities: the breakdown of critical infrastructures as a result of a natural disaster, such as a severe storm, and a human-made emergency caused by an explosion at a big event. In four pilot projects, SIRIOS researchers use coupled simulations to investigate the development and effects of such incidents, while also deriving procedures to strengthen security and societal resilience. At the first annual conference in fall 2023, the researchers showcased the results they have achieved so far: For example, simulations showed possible cascading effects on utilities following a substation failure caused by severe weather. Integrating the simulation data into a situation picture helped to decide whether an affected hospital should be evacuated. In another scenario, a big event was used as an example to simulate how crowds of visitors would behave if passageways were closed, stage performances attracted particularly high numbers of people, and danger warnings were issued.

2nd funding phase of ROBDEKON competence center

Since 2018, the Federal Ministry of Education and Research has been funding the “Robotic systems for decontamination in hazardous environments” competence center (ROBDEKON) as part of the “Research for Civil Security” program. The vision is for robots to perform tasks as autonomously as possible, for example in the remediation of contaminated sites, the dismantling of nuclear facilities, and the recovery of hazardous substances, with the aim of keeping people away from working in the danger zone. The consortium is led by Fraunhofer IOSB and also comprises the Karlsruhe Institute of Technology (KIT), the Robotics Innovation Center of the German Research Center for Artificial Intelligence, the FZI Research Center for Information Technology, Karlsruhe University of Applied Sciences, as well as several industrial partners.

After the ROBDEKON partners initially defined detailed use cases, researched key technologies, and developed demonstrators, the focus in the second funding phase, which started in 2022, has shifted to transferring results into practice and making the center permanent. In practical pilot projects, ROBDEKON cooperates with companies with the aim of putting the developed solutions to the test under real operating conditions. For example, the autonomous 24-ton excavator ALICE proved for the first time that it is capable of mastering complex tasks outside of Fraunhofer IOSB premises: It navigated in a quarry, avoided dynamic obstacles, and successfully completed work tasks such as autonomously feeding a crusher.

3. Organizational development and infrastructure

Fraunhofer IOSB is not only actively developing the state of the art in its various areas of expertise, it is also constantly improving as an organization. This includes reviewing and, if necessary, revising and modifying processes and structures, optimizing procedures and incentive systems, and responding to the requirements of the current times.

Transfer-focused internal research funding
We invest part of our base funding in in-house research, i.e. pre-competitive research projects financed from the institute's own funds. Our Technology Development Program (TEP) has always focused on promoting ambitious, cross-departmental projects that are conducive to strategic portfolio development. We have now further developed this internal program in order to even more strongly incentivize the transfer of technology into application — and thus to the customer.

To this end, the TEP has been expanded into a three-stage model. The basic concept is that R&D ideas worthy of support should be backed by a potential user of the technology right from the outset. They should be geared towards the user's practical requirements so that the transfer will be successful once the R&D work has been completed. Such a potential user, or technology patron, is needed as an external point of reference even before the actual project plan is created and funding application for the TEP started. And the actual TEP phase, which typically lasts one to two years, is now followed by a technology proof of concept phase, which serves to pilot the solution in a real application context, on site at the technology patron's premises. Our researchers' work in this phase can also be funded internally for up to one year.

Updating the HR development concept
In 2022, the decision was made to further enhance Fraunhofer IOSB's existing HR development concept. Since then, a task force has been advancing the work on the actual content. Initially, it focused on the target groups of IT and research scientists. In these occupational fields, the institute faces particularly great challenges in recruiting personnel, making boosting employer attractiveness particularly important here.

As a framework for development opportunities, the HR development concept aims to create attractive career prospects beyond the traditional management career path. The concept outlines three possible specialist career paths. By explicitly formulating the respective requirements, tasks and responsibilities, the roles of "senior scientist" and "senior innovation/application expert," which have existed for some time, are being refined and clarified. A third option, "senior manager of major projects," has been added. Similar concepts are currently still being developed for other target groups, such as those in the area of administration.

Karlsruhe Research Factory and Research Campus
In March 2022, the Karlsruhe Research Factory for AI-integrated Production opened on the Campus East of the Karlsruhe Institute of Technology (KIT) — see IOSB Annual Report 2021/2022. The Cognitive Industrial Systems department (KIS), which was also newly established in 2022 and has close links in terms of content with the activities of the Research Factory, decided to relocate to an office building directly on site. This brings office and laboratory work in close proximity to each other and ensures daily communication with the research factory's other partners. The Fraunhofer IOSB main site in Karlsruhe is still an easy 15-minute walk away. There, the move has freed up space for other departments that are also growing. In addition, the former library has been converted into new offices and meeting rooms.

An even bigger change for the site will be coming in the next few years: The plans for a new building at Fraunhoferstrasse 1, the "Karlsruhe Research Campus", are taking shape. Construction is scheduled to begin in 2026 and the structural design has been entrusted to the the team at the Henn architecture firm. The new building will accommodate new, additional laboratory and office space for our institute. Moreover, and most importantly, the Fraunhofer Institute for Systems and Innovation Research ISI will relocate to the new building on what has been IOSB premises until now, as it has outgrown its current building. Both institutes will conduct joint research in the future, which will boost professional networking and interdisciplinary cooperation. The focus will be on the responsible development and application of artificial intelligence and autonomous systems as well as their economic and social potential.

New cognitive automation research area at Fraunhofer IOSB-INA

With the joint appointment of Dr. Klaus Neumann to the professorship for Collaborative Robotics as of July 1, 2023, Bielefeld University and IOSB's Industrial Automation branch, Fraunhofer IOSB-INA, in Lemgo, have laid the foundation for a strategic collaboration. After studying computer science and completing his doctorate in the field of intelligent systems, Dr. Neumann worked in the field of machine learning and robotics for industrial applications for over nine years — one year as a postdoc, then at Beckhoff Automation. Now, in addition to his professorship at Bielefeld University, he is establishing the new cognitive automation research area at Fraunhofer IOSB-INA, currently located within the Machine Intelligence department (MIT).

Planar robotics offers the opportunity to combine product transportation and manipulation and significantly reduce the machine footprint

Prof. Neumann, what experience do you bring to this bridging role between university and applied research institute?

I have been working in the fields of machine learning (ML) and robotics for many years. My doctorate at the CoR Lab at Bielefeld University was on unifying white box and black box approaches to learning, and controlling different robot platforms. I had extensive contact with industrial applications through the it's OWL leading-edge cluster, which was just starting at the time. When I worked in industry, I was a software developer in the field of motion control, again with a focus on the potential of ML. Later, the emphasis shifted to the integration of ML into industrial automation. Throughout this time, I remained connected to the academic field, for example by attending various conferences and participating in scientific events.

Will the use of ML and robotics in industrial automation remain your research topic in the future?

In my current work, I am focusing on three main areas, which of course overlap to some extent. One topic is autonomous machine learning, with the aim of controlling these machines in an optimally resource-efficient way, preferably in real time. In this context, the aspect of safety always plays an important role. The second area comprises manipulative robotics and robotic assistance for assembly work. Imitation learning is important to me in this regard because it enables simple and intuitive programming of robots, which is becoming increasingly important in view of demographic change and the shortage of skilled workers.

And the third focus?

That is planar robotics. I also became interested in the topic during the time I worked in industry. Movers, a component of planar robots that can not only move and rotate in the plane, but also have additional degrees of freedom to lift and tilt their payload, offer the opportunity to combine product transportation and manipulation and thus significantly reduce the footprint of a machine. This raises many exciting research questions, for example with regard to optimization and swarm behavior.

Spotlight on sustainability

The Executive Board of Fraunhofer-Gesellschaft has set the goal of reducing the organization's emissions by 55 % by 2030 and offsetting the rest. The Fraunhofer-Gesellschaft aims to be climate-neutral by 2045. In addition to a dedicated department at headquarters, climate protection projects and the Fraunhofer Institutes' climate neutrality and sustainability officers (BfKNs) are key elements in achieving this goal. Fraunhofer IOSB has also had a BfKN since 2022, Oliver Warweg from Fraunhofer IOSB-AST in Ilmenau, as well as a deputy, Dr. Thomas Bernard from the Karlsruhe site. The BfKNs hold monthly meetings with the head of administration and facility management staff from all sites to discuss and prepare measures to achieve climate neutrality. They act as in-house ambassadors and points of contact for the topic and are in close contact with Fraunhofer headquarters and the BfKNs at the other institutes. All Fraunhofer IOSB sites are integrated into regional "energy efficiency networks," where the participating institutes set a joint energy-saving target for themselves, which is to be implemented by the end of 2026.

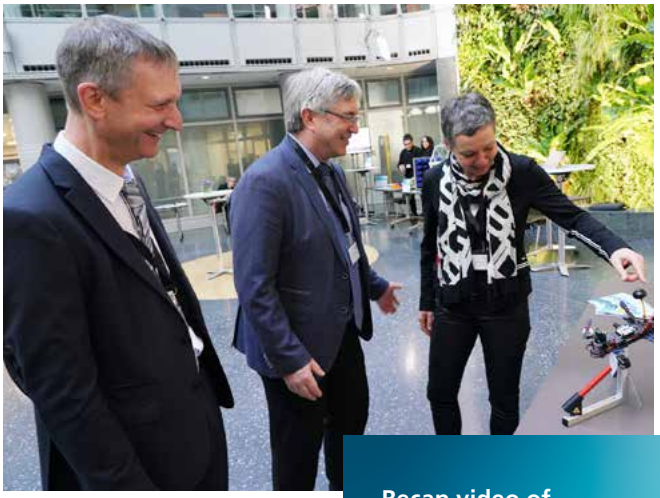
Climate protection projects include LamA® — charging at the workplace, which involves setting up charging stations for electric cars at Fraunhofer sites, and a funding program for photovoltaics (solar arrays). Fraunhofer IOSB has benefited from both of these: Karlsruhe and Ettlingen each have a charging station on the institute's premises. In Ilmenau, the charging facility was put into operation on May 7, 2024, and can now be used by employees. In the long term, this is the aim for the other IOSB sites, too. Through the photovoltaic program, a solar array system was installed on the roof of the institute building in Karlsruhe, which should cover up to half of the daily electricity requirements in the future. Plans call for setting up a similar system for the site in Ilmenau, as an extension to the existing array. In Lemgo, there is a smaller, particularly innovative solar array system in the form of a "smart flower" that aligns itself with the position of the sun.

Furthermore, Fraunhofer IOSB launched a sustainability award in 2022. The call is for actionable concepts that promote sustainability in various categories. All employees are invited to take part, with a total of 10,000 euros in prize money being awarded each year. In the two rounds to date, numerous suggestions have been submitted, ranging from the procurement of company bicycles and sustainable alternatives for the disposal of decommissioned computers to various measures for more biodiversity on the institute's premises.

Future Security 2023

As in 2019, Future Security 2023 was once again organized by Fraunhofer IOSB — the four-year break in between was due to the pandemic. Future Security is a forum of the Fraunhofer Segment for Defense and Security VVS that serves as a national meeting platform for researchers, experts and other stakeholders from science, industry, and politics. With around 170 participants, our venue, the Fraunhofer Forum in Berlin, was fully booked.

The theme of the event was "Our security is indivisible! Do we need to consider internal and external security together?" Invited speakers during the first (half) day included the Fraunhofer president, high-ranking representatives from the German federal ministries of research and defense, officials from the police and disaster control authorities, the president of the Federation of German Security and Defence Industries (BDSV), and the spokesperson for the new Fraunhofer SIRIOS center in Berlin. There was little disagreement that internal and external security must be considered in combination — but there was plenty of discussion about how this should be done and, in particular, how it should be financed. Day two then focused on specialist sessions on the topics of "Quantum technologies", "Drone detection and countermeasures" and "Resilience: How to emerge stronger from disruptions".



Recap video of INDIN 2023 at:

4. Outreach events

After only being able to report on the first tentative signs of a return to in-person events in the last progress report, which was published in 2022 while the pandemic was subsiding, things have returned to normal in the reporting period covered by this issue. We have organized and successfully held a number of events ourselves: an AI Systems Engineering Day for Production at the Karlsruhe Research Factory, the Image Processing Forum 2022, the 6th Conference on Optical Characterization of Materials (OCM), the MAROS (Maritime Robotics and Sensors) Conference, Fraunhofer IOSB's Defense Technology Day, and several more. Below you can read more about three special events.

Along with our own events, we were present at numerous trade fairs and specialist events — including Hannover Messe, E-world energy & water, AFCEA trade exhibition, CONTROL, LASER, and many more, as well as numerous career fairs. A comprehensive list of our activities in this area can be found in the online appendix, see p. 96.

INDIN 2023 in Lemgo

Together with the Institute for Industrial Information Technology at the OWL University of Applied Sciences and Arts, Fraunhofer IOSB-INA succeeded in bringing the 20th edition of the IEEE International Conference on Industrial Informatics, INDIN'23, to Lemgo. More than 250 scientists from all over the world came to the historic Hanseatic city in mid-July 2023. They presented groundbreaking research results and innovative ideas and were impressed by the mix of the picturesque historic city backdrop and Lemgo's modern infrastructure for knowledge and technology transfer (including the Innovation Campus Lemgo and SmartFactoryOWL). A recurring topic at the conference was the importance of AI in the field of industrial production. Fraunhofer IOSB organized a special session on AI systems engineering in industrial automation.

Formal inauguration of Building C in Ettlingen

Selected senior representatives from the federal ministry of defense, city administration, municipal council, and the relevant authorities accepted our invitation and attended the official inauguration of Building C at the Ettlingen site in September 2023. The modular construction was erected for the new, dynamically growing Laser Technology department. It houses two laboratories and 18 office workplaces and has been filled with life for quite some time. After several welcoming addresses, site director Prof. Marc Eichhorn's keynote speech highlighted the importance of Fraunhofer IOSB's laser research for Germany's technological sovereignty. His speech was then followed by a presentation by the head of the Laser Technology department, Dr. Christelle Kieleck, providing a review and outlook on the development of the institute's Ettlingen site in this context. There was a consensus among the participants that Building C should be retained beyond the five-year period of use initially envisaged and approved — at least until the planned large extension building for Fraunhofer IOSB Ettlingen is finished.

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 of Optronics, System Technologies and Image Exploitation IOSB.

The core competences

The institute's core areas of competence are spread among 17 scientific departments. 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.

According to their strategic and scientific orientation, our departments are constantly evolving. In 2022, the new department "Cognitive Industrial Systems (KIS)," headed by Dr. Julius Pfrommer, emerged from the research group "Cyberphysical, Distributed Systems".

In 2024, Dr. Elisabeth Peinsipp-Byma, head of the Interactive Analysis and Diagnosis department, moved to Fraunhofer headquarters. Under the leadership of Dr. Michael Voit, the department was refocused and relaunched under the new name "Human-AI Interaction (HAI)".

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.

Knowledge transfer with universities

The institute has locations with various research foci throughout Germany. Karlsruhe, Ettlingen, Ilmenau and Lemgo are the main sites. These are complemented by smaller branch labs in Berlin, Görlitz, Oberkochen and Rostock, which take advantage of local cooperation opportunities, and the liaison office in Beijing. 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). Most of the other sites maintain similarly close ties to local universities, resulting in a Chair in Energy Usage Optimization at the Ilmenau University of Technology, the new Chair in Collaborative Robotics at Bielefeld University (see page 16) and various chairs at the universities of applied sciences of Schmalkalden, Zittau/Görlitz and Ostwestfalen-Lippe, while the research groups in Berlin and Rostock are the result of joint ventures with other Fraunhofer Institutes.

Core competences and structure

Optronics

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

- Laser Technology | LAS
- Optronics | OPT
- Signatorics | SIG
- Visual Inspection Systems | SPR

System Technologies

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

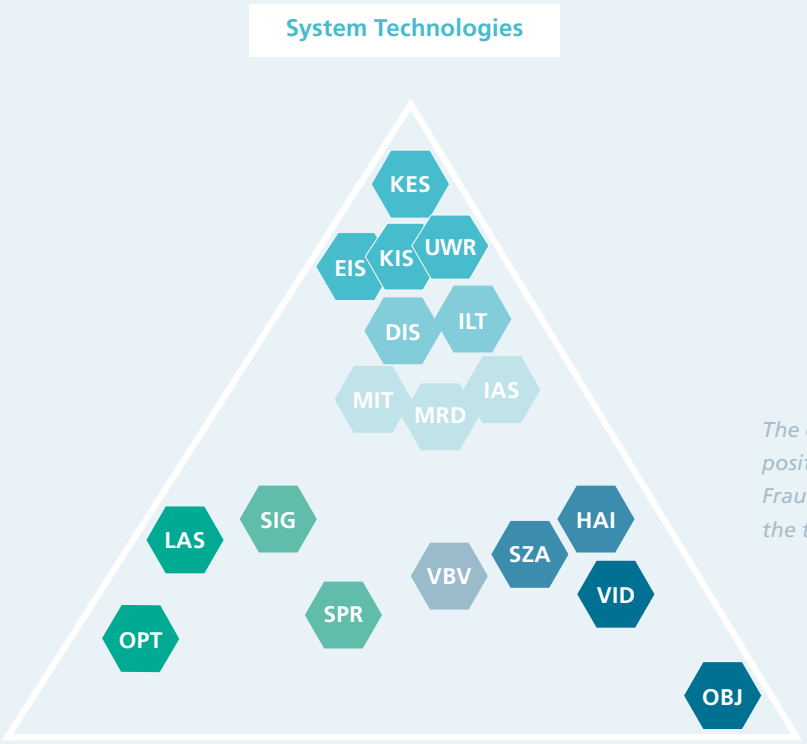
- Cognitive Energy Systems | KES
- Cognitive Industrial Systems | KIS
- Digital Infrastructure | DIS
- Embedded Intelligent Systems | EIS
- Information Management and Production Contro | ILT
- Interoperability and Assistance Systems | IAS
- Machine Intelligence | MIT
- Systems for Measurement, Control and Diagnosis | MRD
- Underwater Robotics | UWR

Image Exploitation

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

- Human-AI Interaction | HAI
- Object Recognition | OBJ
- Scene Analysis | SZA
- Video Exploitation Systems | VID
- Variable Image Acquisition and Processing research group | VBV

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

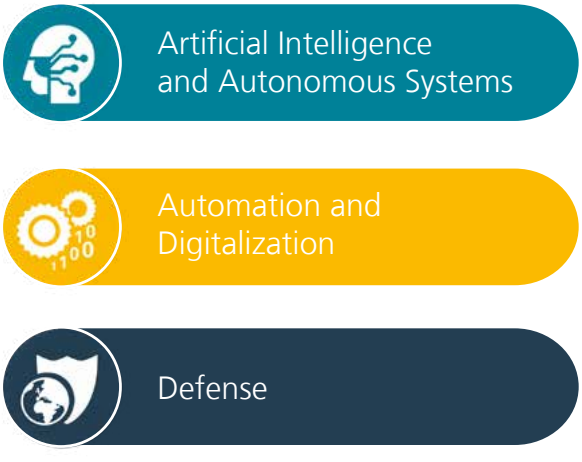
As an institute committed to applications-oriented research, we source roughly one-third of our budget from projects for clients from a range of industries, including both private-sector companies and public-sector bodies such as municipalities or environmental and security agencies. A further one-third 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



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

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.

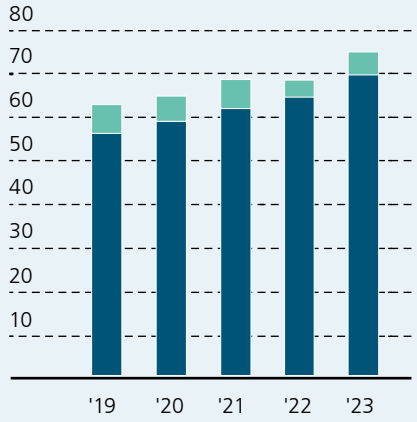
Tailored to your needs

If you are interested, please contact the appropriate business unit or department through the contacts listed in the respective chapter. We look forward to talking to you and will be happy to make you an offer tailored to your specific needs.

Key figures

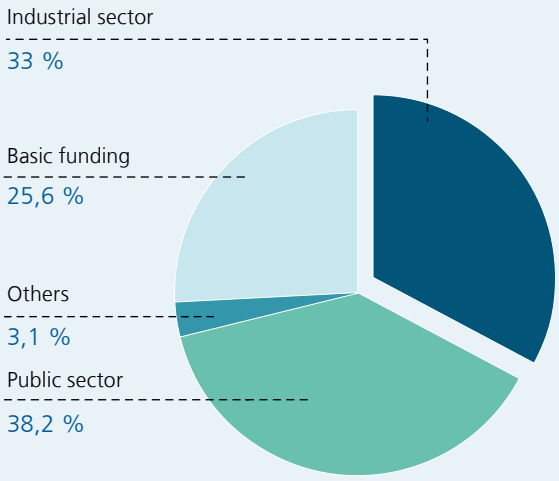
Business expenses

How much money did we spend?



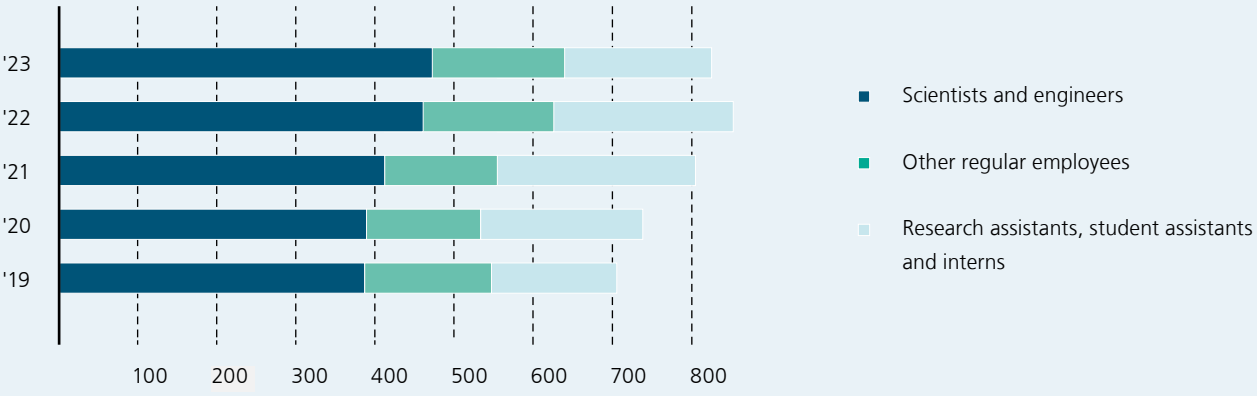
Funding

Where did the money come from (in 2023)?



Staff

How many persons worked at Fraunhofer IOSB?



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. Jürgen Moßgraber

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

IAS | Interoperability and Assistance Systems
Dr. rer. nat. Jennifer Sander

KIS | Cognitive Industrial Systems
Karlsruhe Research Factory
Dr.-Ing. Julius Pfrommer

HAI | Human-AI Interaction
Dr.-Ing. Michael Voit

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

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

Berlin

SIRIOS | Fraunhofer Center for the Security of Socio-Technical Systems
Dr.-Ing. Markus Müller

Görlitz

IT Security for Critical Infrastructures Energy and Water (research group)
Prof. Dr.-Ing. Jörg Lässig

Oberkochen

Active Laser Fibers (research group)

Dr. Christelle Kieleck

Rostock

SOT | Smart Ocean Technologies (research group)
Prof. Dr.-Ing. habil. Thomas Rauschenbach

Administration

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

IT security
M.Sc. Marco Feuchter

Staff department

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

Press and Communications
Dipl.-Phys.
Ulrich Pontes

Beijing Representative office China
Dipl.-Ing. Hong Mu

Pooling expertise

As part of the Fraunhofer-Gesellschaft, Fraunhofer IOSB is affiliated with the leading applied research organization, which operates 76 institutes and research units at locations in all of Germany's states. Since 1949, it has been Fraunhofer's mission to strengthen the competitiveness of the German and European economies and their regional research and innovation.

Concentrating on future-relevant key technologies and transferring ideas and research findings to industry, business and society, Fraunhofer helps to shape the innovation process. Fraunhofer aims to have an impact in areas such as digitalized value creation, a fully circular economy, and security and a resilient society — and with its more than 30,000 employees with backgrounds in the physical and life sciences, engineering, and social and economic sciences and an annual research volume of some three billion euros, it also has the strength and resources to bring about positive change.

Fraunhofer IOSB participates in this strong community in a variety of ways and actively participates in several areas aligned with its size and thematic range:

Fraunhofer Groups

One central aspect of cross-institute cooperation is the research groups formed by institutes covering related disciplines and topics. These groups act as a unified whole on the R&D market, combining the skills and abilities needed to develop system solutions with cross-industry impact. The chairs of the Fraunhofer Groups sit on 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.**

Numerous institutes have come together to form the **Fraunhofer Segment for Defense and Security VVS**, based not on specific areas of expertise but rather on shared applications. Even with this difference in aim, Fraunhofer VVS is similar to the groups themselves in terms of its importance and weight within the Fraunhofer-Gesellschaft Fraunhofer IOSB was a founding member and has also been the chair since 2015 (see p. 32).

Fraunhofer Alliances

Interdisciplinary alliances have been established between institutes to enable them to jointly develop and market solutions for specific business sectors. These alliances address industries that are key to Germany's and Europe's power of innovation. They are a one-stop shop for specific areas of expertise, with a single point of contact.

Fraunhofer IOSB is a member of the following Fraunhofer Alliances, with individual departments participating in each case:

Fraunhofer-Gesellschaft — 75 years of innovation

Over
6,200
customers from the private sector

... of which around 60 percent are small- and medium-sized companies.

Over
30,000
employees

In 2023, the recruitment rate for female scientists increased to 30 percent (overall approximately 25 percent of research staff are women).

76
institutes

... organized into nine groups.

2
patent applications every workday

Fraunhofer ranks among the 10 to 20 most active patent applicants every year.

90 %
of our institute directors hold a professorship

They combine university research with applied research and development at Fraunhofer.

Approximately
30
spin-offs per year

... over 500 since 2000. Roughly 80 percent are still active after ten years.

Over
7,600
active patent families

Fraunhofer is an EU-wide leader in the establishment of standards.

2.6 billion
euros of revenue from contract research each year

Demand from the private sector and society is driving growth.

Real innovations.
#WeKnowHow

- Agriculture and Food Industry
- Automobile Production
- Aviation and Space
- Big Data and Artificial Intelligence
- Building Innovation
- Energy
- Transport
- Water Systems

In addition to these Fraunhofer Alliances, the institute is also part of the Fraunhofer 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.

Fraunhofer Clusters of Excellence

Acting as a "virtual institute" spread over multiple locations, the Fraunhofer 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 **Karlsruhe Mobility — KAMO**, 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.

The High-Performance Center **Sustainable Ocean Business** in Rostock focuses on solutions for underwater technologies.

Cooperation highlights

In Rostock, Fraunhofer launched the cross-institute **research group Smart Ocean Technologies SOT** in 2020 as part of the newly emerging Ocean Technology Campus. Fraunhofer IOSB departments in Karlsruhe and Ilmenau are part of the group, and 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. The goal of the interdisciplinary research group is to develop future-oriented underwater technologies for sustainable use of the oceans. The Fraunhofer Digital Ocean Lab offers a fully equipped nearby underwater testing field in the Baltic Sea for testing the technologies.

Similarly, multiple institutes have pooled their expertise to form the **Fraunhofer Center for the Security of Socio-Technical Systems SIRIOS** in Berlin. Launched in 2022, the center makes complex security scenarios tangible and controllable in order to increase security and resilience in society. To do this, SIRIOS creates a unique research, testing and training environment for coupled simulations of complex security scenarios such as natural disasters or attacks. Departments from Fraunhofer IOSB in Karlsruhe and IOSB-AST in Ilmenau are involved here as well. 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.

Security and resilience in a very particular area are also the topic of the **Cybersecurity Training Lab (LLCS)**, a cooperative initiative that brings together Fraunhofer institutes, Fraunhofer Academy, and selected higher education institutions. The initiative comprises 17 labs, all covering different topics. Fraunhofer IOSB is responsible for two of them: the LLCS focusing on **industrial production**, which has locations in Karlsruhe and Lemgo, and the lab that deals mainly with **energy and water supply**, in Ilmenau and Görlitz.

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
  - Learn from small, relevant data
  - Development and optimization of algorithms
- **AI and the Human**
  - Speech and dialog systems
  - Intelligent agents
  - Multimodal, collaborative systems
- **Certified AI**
  - Explainability, traceability
  - AI safeguarding (safety/security), attack defense
  - Standardization
  - Human control of AI
- **AI and Hardware**
  - Neuromorphic computing
  - Hardware/software co-design
  - Quantum AI and -algorithms
- **Generative AI and Large Language Models**

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
- Reconnaissance 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
- **Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR,** Radar — a key technology

ASSTA 3.1-Tornado.

- **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 Applied Optics and Precision Engineering IOF,** From highly secure communication to tailored laser technology
- **Fraunhofer Institute for Transportation and Infrastructure Systems IVI,** Algorithms for risk analysis, situation evaluation and decision-making support
- **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

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

Deputy chairman
Univ.-Prof. Dr.-Ing. Dr. rer. pol. habil. Michael Lauster, Fraunhofer INT

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

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

vvs.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.

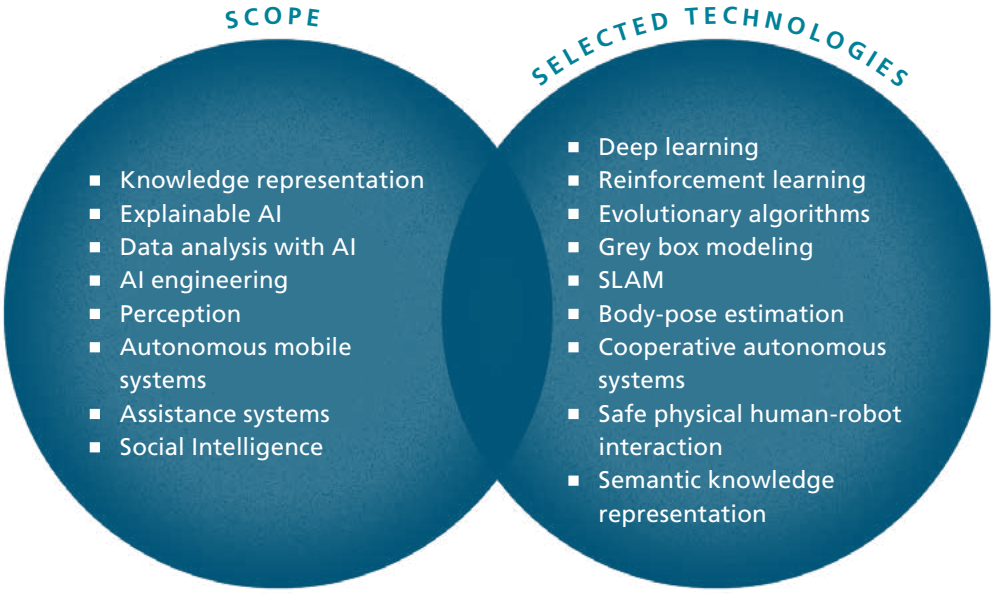
Artificial Intelligence and Autonomous Systems

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

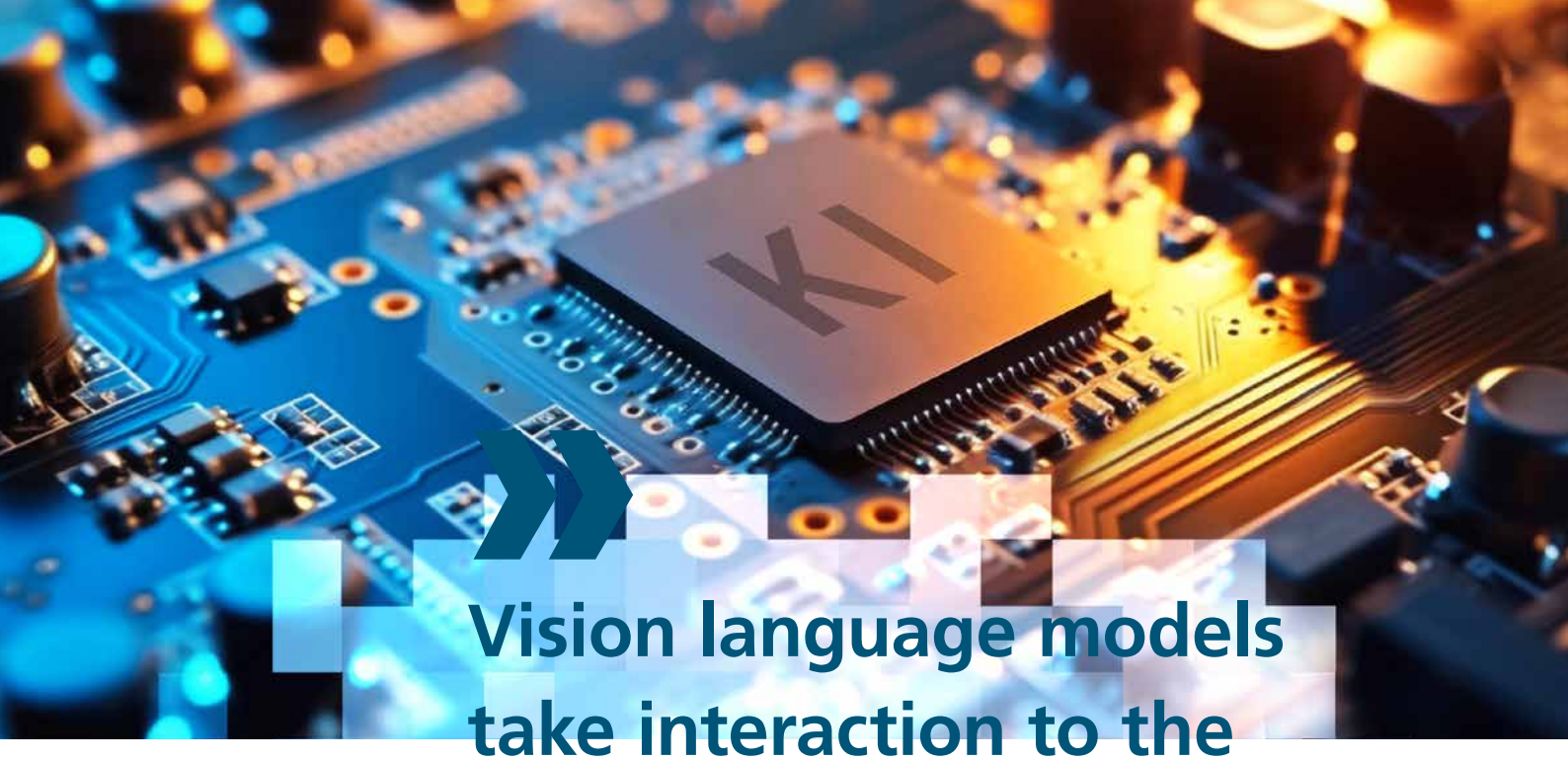
Spokesperson
Dr.-Ing. Michael Voit
Phone +49 721 6091-449

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

iosb.fraunhofer.de/ki

Departments involved

- DIS
- EIS
- HAI
- IAS
- ILT
- MRD
- MIT
- KES
- VID
- UWR



Vision language models take interaction to the next level«

How artificial intelligence with new sensory modalities can support humans even more effectively across different tasks and situations

Dr. Voit, AI chatbots have been making waves for over a year now. How important is this as a factor in the AI and Autonomous Systems business unit?
Michael Voit: ChatGPT and other generative language AIs are based on so-called large language models. We do track developments in these models and how they can be used in our application domains closely, of course. But for us as an institute working in image processing, it's especially interesting to go one step beyond and start to look at vision language models (VLMs), which are AI systems that are not limited to language as a modality. They also process visual input at the same time. So you might think of us as preferring to work with "chatbots with eyes" than with purely language-based chatbots. This kind of AI can grasp situations on a more comprehen-sive basis, much like a human combines various sensory impressions to form a holistic concept. For us, that offers an opportunity to take assistance systems and their interactions with humans to the next level.

What are potential applications?
Our various departments research a wide range of different use cases for VLMs. In the e-learning space, we would like to feed our semantic search engine for learning content with images as well in the future. Then you could search along the lines of, "I don't understand this figure — what learning material could help me?" In the area of military reconnaissance, the goal is to automate image exploitation and subsequent preparation of reports. And for cars, our goal is to develop voice assistants that also take what they see into account. So, the assistant could do things like tell when a vehicle occupant is struggling with motion sickness and offer tips instead of waiting to respond until the person says they have an issue.

What is your approach to getting these kinds of VLMs?
We don't have the resources to create a big VLM of our own, but adjustments to existing models are possible with relatively little effort and expense via few-shot learning, meaning not a lot of training data is needed. That's why we know and test the available models, evaluate them with an eye to our application domains and use cases, and optimize the suitable candidates. Linking existing large models with our own specialized systems is another promising approach. In the automotive segment, for example, we use our Occupant Monitoring System, which is opti-mized to recognize poses and activity based on images, and we feed that output into a language model. It is even conceivable that we might be able to add further modalities, supplementing the system with acceleration sensors, for example.

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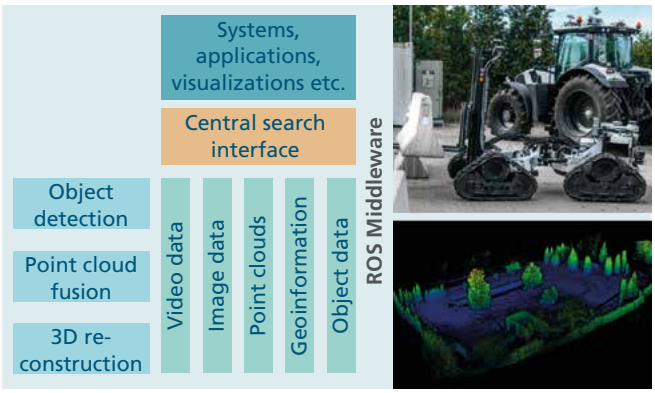
Operating machine learning applications productively requires continuous monitoring, adaptation, and maintenance.



Overview of the components of the MUSAL ecosystem, sample autonomous mobile systems, and generated point cloud data.

Continuously improving and deploying machine learning applications — MLOps

Like all software, AI applications are constantly evolving. It is hardly ever the case that the scope of application, desired functionality, and all of the boundary conditions that apply are known in detail at the start of the project. New requirements as well as requests for adjustments arise over time, especially once the system is live. In the case of machine learning applications, additional challenges make it especially important to pursue a structured approach both during initial development — the PAISE® (Process Model for AI Systems Engineering) methodology is useful here — and in live operation, during the evolution of the software components and continuous training of machine learning models. This is the only way to ensure that further developments beyond the prototype stage can ultimately be taken live into productive environments.

This structured approach is the subject of the MLOps paradigm (which is named by analogy to the DevOps concept in software development). A project of the same name aims to harness our experience across a whole host of AI application domains to realize MLOps with maximum effectiveness and automate it as far as possible. To that end, we have developed a software suite that incorporates a wide range of tools for creating machine learning applications and training the ML models. Our toolkit makes versioning of various model releases possible, including the associated quality criteria, while also supporting the transition to productive operation and monitoring the application and its results, for example to detect model drifts. The tool collection also includes components developed at Fraunhofer IOSB for sensor data management (FROST®), video data annotation (ANTONN), and explainability of AI methods (XAI Toolbox).

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Cooperative environmental modeling for autonomous systems and surveillance tasks

Mobile autonomous systems make it possible to capture their environment using various sensors. The data collected include 3D point clouds, images and videos, and resulting object detections. Ensuring that these kinds of data do not remain siloed on individual systems requires efficient exchange and storage mechanisms. In this way, the data can be made available and usable in a standardized way so they can contribute to a holistic description of the existing situation. The internally financed MUSAL research project is dedicated to the challenge of conceptualizing and implementing this kind of structure.

MUSAL's goal is thus to ensure seamless cooperation between different systems in a broad array of project contexts. This is achieved by exchanging and further processing relevant data and using this information to optimize the way the situation is presented. Beyond that, the project also aims to give operators a full overview with expanded options for accessing historical information from all systems, thereby laying a solid foundation for decision making.

Toward this end, a distributed information system with specific data sinks, defined interchange formats, and an overarching search function was created as part of MUSAL. In addition to sensor data, prior knowledge and geoinformation can also be leveraged effectively. Containerized services make the software that was developed readily deployable. It also provides services such as point cloud fusion and generation of point clouds from image data in a central location.

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Drone flight: 3D terrain modeling to estimate biomass.

FarmerSpace — a space for experimentation with new and digital approaches to crop protection

FarmerSpace focuses on the use of digital technologies for crop protection. In this project, Fraunhofer IOSB-AST in Ilmenau has teamed up with the Institute for Sugar Beet Research and the section of Agricultural Engineering, both at the University of Göttingen, and with the Lower Saxony Chamber of Agriculture to investigate how leaf diseases and the spread of weeds can be detected at an early stage and targeted protective measures can be taken. Sensors, robotics, and data-driven solutions offer the potential to minimize the use of chemical crop protectants without adversely affecting crop yields.

In this context, we are investigating and evaluating sensor and data transmission systems, radio sensor networks, and options for satellite communication. In particular, we are developing an innovative method of estimating biomass based on remote sensing data. Drone-supported lidar and radar sensors are specifically being used for this. This approach depends to a crucial degree on the quality of the underlying digital terrain model, which means that precision 3D surveying of cropland is an area of focus as well. With this in mind, we conducted a 3D challenge within the project to evaluate the various approaches.

FarmerSpace is due to run until 2025. It is one of 14 experimental fields throughout Germany that are receiving funding as part of the digital transformation strategy pursued by the German Federal Ministry of Food and Agriculture (BMEL). The German Federal Office for Agriculture and Food (BLE) is the project sponsor.

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Demonstration of autonomous recovery of hazardous goods in a complex scenario.

Converting construction machinery for effective rescue operations

When major incidents such as industrial accidents or natural disasters occur, rescue teams are faced with significant challenges. The rapid removal of potential hazards is crucial to the efficient search and rescue of victims. This is where our project comes in: By using robotic technology, the risk to rescue workers is minimized and rescue operations can begin at an early stage.

We addressed this challenge within the now completed AKIT-PRO joint project funded by the German Federal Ministry of Education and Research (BMBF). Our innovation lies in retrofitting construction and work machinery to convert them into automated rescue equipment: Our autonomy kit quickly equips locally available machines, such as excavators and tractors, with sensors and other components, turning them into unmanned recovery vehicles. Featuring functions such as autonomous navigation and 3D-based object manipulation, it provides the best possible support for rescue teams in quickly eliminating sources of danger.

In the bigger picture, AKIT-PRO explored a new type of recovery chain consisting of highly automated recovery vehicles, support shuttles, and communication components. Thanks to its modular design, there is no need to keep special equipment in stock all over the world, but instead, the necessary components can be procured and qualified on site as required. The project thus makes a significant contribution to improving disaster management and protection of rescue workers.

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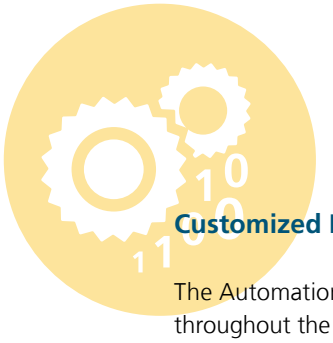
Automation and Digitalization

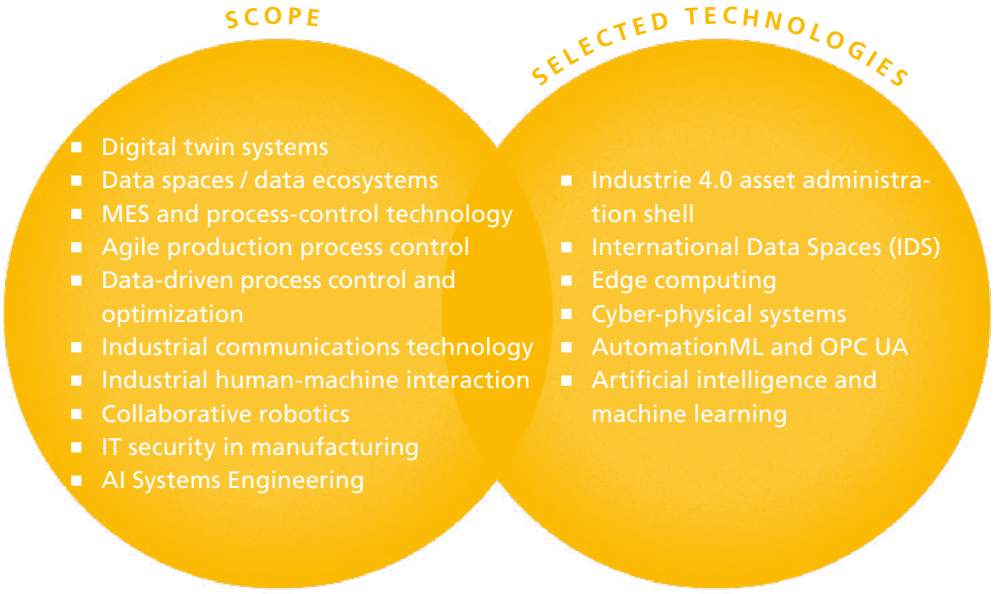


Customized IT for networked production ecosystems

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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- ILT
- MIT
- MRD
- KES
- SPR

Data truly delivers added value when companies share it for specific purposes«

Manufacturing-X and associated projects: How the digital transformation is advancing the twin causes of economic efficiency and sustainability

Dr. Sauer, why should an SME think about digital twins or data ecosystems?
Olaf Sauer: As we strive for sustainability and the ideal of the circular economy, every company that makes products will have to disclose information about their carbon footprint going forward, and soon, they will also have to create digital product passports, if at all possible based on standards. An asset administration shell, or AAS, is one way to do this. But regulatory matters alone aren't a great motivation to use digital twins. Data can't truly deliver added value until companies share it with customers, contractors, and suppliers for specific purposes. This unlocks potential we can only dream of today. For example, a material manufacturer has data on the production process and quality of their materials, which a processing company could use to set the parameters for their production equipment more efficiently and effectively, potentially reducing waste or accelerating the start-up process. Within data ecosystems, companies can share data according to defined rules so everyone benefits in the end.

What is Manufacturing-X's role in this?
Manufacturing-X is an overarching program to build industry-specific data ecosystems for diverse sectors. Examples include mechanical engineering, with the Factory-X flagship project, Aerospace-X for the aerospace industry, and Silicon-X for semiconductors. Because all of them build on the same infrastructure, they're interoperable, so companies only have to sign up with one of these platforms to share data or get data from others. Digital twins, or more precisely, submodels of digital twins help to standardize the sharing of data, whether that's horizontally, meaning along the supply chain, or vertically, which refers to runtime data of machinery and equipment. On the other hand, every industry has specific use cases stemming from factors like internal industry regulations, and those require proprietary software elements in the form of business applications.

How does IOSB come into play?
Fraunhofer is involved in building these data ecosystems on two crucial points. We develop some of the business applications, on the basis of open standards, so companies can easily incorporate them into their IT infrastructure. And we develop software services for the base infrastructure. Here, all partners rely on open source solutions because although the infrastructure is crucial to building and operating the data ecosystems, it isn't relevant in terms of competition or customers. So everybody shares in the effort and expense of developing these services. And then we can take what we learn from these activities and put it to work in transfer and customer projects as well.

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With optimized communication for a newly developed control hardware, we ensure an efficient and more stable energy feed-in.

Ultra-high-speed communication for wind turbine grid feed inverters

Climate change is currently posing a huge challenge for highly efficient production of electricity from renewable sources. In this context, Fraunhofer IOSB-INA has been working for wind turbine manufacturer Enercon since 2020 to develop an innovative form of ultra-high-speed communication for what are known as "E-nacelles," in which the power electronics are built right into the nacelle itself. The real-time communication systems available on the market have been unable to meet all of the stringent requirements (ultra-fast transmission times, low system costs, future viability, and use of standardized base technologies) at once.

Through its research, Fraunhofer IOSB-INA has devised an optimized communication protocol and demonstrated feasibility both experimentally and using simulation techniques. Afterward, the design, which is based on field-programmable gate arrays (FPGAs), was ported to the control hardware newly developed by Enercon. To prepare for use in the field, we incorporated the solution into hardware-in-the-loop systems.

Enercon commissioned the first wind turbine with the new hardware in Staphorst, the Netherlands, in late 2022. The inverter that Enercon has developed can control active and reactive power feed-in in real time and with much greater accuracy than ever before. It helps to ensure that the energy feed-in is efficient and more stable overall.

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Digital product passports, realized in digital twins, provide the product information needed for a functioning circular economy.

Digital ecosystem for flexible, sustainable supply chains

A functioning circular economy requires an interoperable exchange of information on products and supply chains. It must be possible to purchase components flexibly, along with choosing the various paths a product may take at the end of life: What exactly is taken apart, reused, or recycled, and how?

To overcome these challenges by way of example, the Catena-X innovation project has created a data space for the automotive industry and its complex supply chains. One part of it is a digital manufacturing-as-a-service ecosystem based on the Smart Factory Web reference architecture developed by Fraunhofer IOSB. This platform enables matchmaking between demand and supply of factory capabilities, visualized in digital twins. This makes it possible, for example, to find companies that can dismantle certain kinds of batteries. The product information needed for this — in this case, details like battery composition — is contained in the digital product passport (DPP). This also involves a digital twin, which is administered via a DPP-based supply chain information management system.

The digital twins are represented through asset administration shells, which can be provided by the FA³ST service also developed by Fraunhofer IOSB. FA³ST is open source. It realizes type 2 asset administration shells that can be used to interoperably exchange and interpret standardized submodels (e.g., for DPPs).

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Our extensive experience is incorporated into a new holistic resilience monitoring approach.

Cyber resilience monitoring in industrial automation and control systems

Cyber resilience is seen as the next step in IT security and focuses primarily on incident response and restoring process capability. Appropriate monitoring of process-carrying automation systems and infrastructures is necessary to achieve cyber resilience. CyReM-ICS, an internally funded pre-competitive research project started in 2023, addresses this need by transferring existing approaches to anomaly detection into a holistic monitoring system. The system collects various input data within process infrastructures and uses it as a basis for calculating defined metrics for the resilience assessment of the process networks.

For the target system, the necessary database for a meaningful resilience assessment must be defined based on a system analysis. Open-source detection systems are used to collect the needed data on network traffic and devices. Initial methods to obtain additional information by using active probing have already been integrated and will be updated successively. Collected information is transferred to a central data management system, a security information and event management (SIEM) system. As cyber resilience goes beyond just security and also emphasizes incident response, we are also including advisories.

Predefined resilience parameters and metrics are calculated on the basis of the status information obtained from the devices and are used to evaluate and quantify the resilience status of the systems. External data sources, such as vulnerability information, are evaluated and integrated into the overall system using cyberthreat intelligence approaches.

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Integrated cameras in our Halodome system detect any anomalies on products like this tea pot, our demonstration object.

Halodome — low-cost AI- and camera-based anomaly detection for quality assurance

Quality assurance (QA) is an important part of production, helping to boost production quality, ship defect-free products, and minimize the costs of rework and repairs. But automating QA can often be a challenge. Even if it is possible, it may be expensive, time-consuming, or programming-intensive.

Halodome is an AI-based solution that uses integrated cameras to quickly learn what a correct component is supposed to look like, based on just a few training examples. The system subsequently detects any anomalies and displays them intuitively in the camera image. The human operator can check the result, override any false positives or false negatives from the AI, and even feed the final evaluation back into the system for further training. Interaction takes place via a touch-based monitor — or the detection results are projected directly onto the component, where the human operator can interact using touch gestures and adjust the results intuitively. Voice recognition will also be an option in the future. Halodome can be used in various QA applications. Although it is an AI system, the training process is simple because it does not require an extensive training database.

In this way, Halodome enables low-cost quality assurance for new components as long as anomalies are recognizable in the camera image. The system is user-friendly and learns from comments from human operators on an ongoing basis to make it more robust. The human operator retains the final authority for the checks.

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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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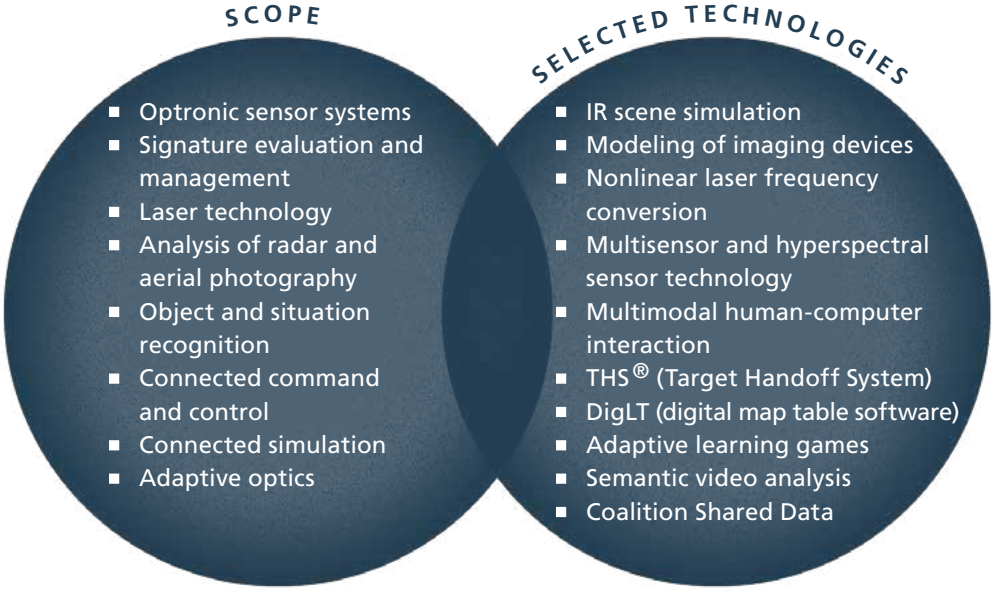
- LAS
- OBJ
- OPT
- SIG
- SZA
- VID



To put innovations to work quickly, we need more agile forms of cooperation«

What contributions we can make as a Fraunhofer institute to advance the transfer of research findings into real-world use within the German armed forces

Dr. Sander, since Chancellor Olaf Scholz announced the "Zeitenwende", an epochal tec-tonic shift, dual use research has received a lot of positive attention in Germany. Is the Bundeswehr on the cusp of a golden age of technological innovation?
Jennifer Sander: At Fraunhofer IOSB, just like Fraunhofer as a whole, we have long stood for a holistic understanding of security that takes military, criminal, technological, and natural threats equally into account. Our research deliberately taps into synergies between the various areas, and we're delighted if this approach, which we think is absolutely reasonable, has won more wide-spread support than previously. Many areas are currently giving rise to research findings and resulting technological innovations with a great deal of military relevance, so it's important to harness those capabilities for the armed forces as well. They include artificial in-telligence, autonomous systems, and hypersonic and quantum technologies, to give just a few examples.

But for the Bundeswehr to be able to derive increasing and timely benefits from these kinds of scientific advances and technological innovations, we think there is not so much a lack of targeted research as a lack of improved ways to transfer existing research findings into real-world practice.

Can you expand on that?
Over and over again, we see how hard it is to translate useful findings from the field of research and technology into actual use. There are a number of structural factors that make it more difficult. For example, we've had past experiences where a research and technology client will say, "Great, we've gotten where we wanted to with this subject, now let's put it into action" — but then we hear from the procurement side that it will be a few years before the demand actually materializes or can be identified with sufficient specificity. And yet, swiftly putting the results to work could help gain greater clarity around concrete use scenarios and needs, and thus to specify and update the further requirement situation early on.

If and when the procurement process does get under way, it remains lengthy and difficult. Formulating the exact requirements right at the start also requires excellent knowledge of the subject matter, including in technical terms, along with an understanding of the potential and the possible usage scenarios. There also seems to be a tendency to formulate things right from the start with all the bells and whistles, detailing every little aspect. However, it's hugely difficult to specify a system on paper in such detail that it actually

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does meet the troops' practical needs down the road and align with their future missions.

What do you suggest?
We need more flexible, more agile forms of collaboration so we can provide better support in putting innovations to work as fast as possible and exactly how they are needed. One point of departure could be to get the opportunity to quickly implement precompetitive, ready-to-use prototypes. Especially when it comes to fast-paced technologies like those in the fields of AI and autonomous systems, there should also be an iterative process to rapidly develop solutions that are already usable while further or more complex features are still under development. When co-creation is put in place — and by that I mean close, continuous interlinkage between R&D, industry, and the entities that require solutions — and when new technological possibilities are made tangible and understandable to users quickly and user feedback is invited, that's where you see success in developing demand-driven solutions and putting them to use right away. Of course, modular architectures, open interfaces, and standards are also important so that systems remain interoperable, expandable, and adaptable. Otherwise, you see proprietary solutions, which are another obstacle to future innovation, and ultimately also for military cooperation in alliances such as NATO.

Are there success stories we can learn from?
At Fraunhofer IOSB, we have realized various systems that are in use within the German armed forces and internationally as well. They include the ABUL video exploitation system, which supports processing and exploitation of drone images with a variety of assistance functions, including a range of newly introduced ones and some based on AI. Another example is the Digital Map Table (DigLT), a software system for shared situation visualization and analysis, which has also been in use for years even as it evolves. The third aspect I would mention is the Coalition Shared Data (CSD) technologies, which make it possible to store, retrieve, and distribute data in multinational and joint reconnaissance systems.

This example shows how a more agile approach could be designed: International and interdisciplinary cooperation and an exercise-driven approach were the focus early on during the phase when the fundamental requirements, concepts, and specifications were being mapped out. Operational and technical stakeholders (decision makers, soldiers, technicians, and software specialists) met regularly for interoperability exercises, which also used real sensors and platforms. In the process, the current status was put to the test in practice, so any discrepancies, pain points, misaligned developments, and areas with potential for improvement were identified early on and adjusted accordingly in the following iteration. This allowed for successive improvements in the solutions before they were transitioned into standards and then implemented in the form of operationally hardened systems. It would be desirable for this approach to be utilized in the further development of CSD technologies and conceptualization of these solutions for new scenarios in the future as well.

But you also want to apply the same approach to many other areas?
I'd put it in somewhat broader terms. One of the capabilities that we at Fraunhofer can contribute to the innovation process is an agile approach in which interim iterations like concepts, scenarios, and prototypes are put to the test by stakeholders at various stages to ensure that they are fit for purpose. Another potential contribution is rooted in our expertise on systems and system interoperability: We can help identify compatibility problems as early as possible. And that, in turn, helps to plan development and procurement activities to be more resilient and implement them with less friction.

Do you have any additional suggestions?
At Fraunhofer IOSB, we do a lot of work with simulations and digital twins, including of the battlefield. Or, to flip that around a bit, we can offer solutions to test things that have not yet been put into practice at all in the real world. This makes it possible to test potential uses, efficiency, performance, and even the interoperability of systems virtually, before they are actually built. In addition to this, such a digital twin has many other advantages across the entire life cycle once the system exists in the real world.

I also think at the post-simulation stage, living labs are a helpful approach. Our institute operates and collaborates on these kinds of labs in various thematic areas. A living lab, or regulatory sandbox, is a structure for trying out new things in one location for a certain period, under conditions that are as realistic as possible, in ways that would be limited by the general laws that are already in place. So, certain difficult aspects are factored out at first to advance innovations — and, of course, also to determine the best way to approach these tricky points to enable widespread, normal use of the new technologies in the end.

Visualizing the temporal dimension of situation evolution

Time plays a key role in military situational planning. This dimension makes it possible to organize and coordinate the sequence of military operations. The ability to optimally use and communicate the time-related aspects of planning requires suitable tools that can take the aspect of time into account from the data storage side and also in terms of visualization.

Conventional situation maps, whether analog or digital, typically present a static situation. They are snapshots of a moment in time. Often, people end up using multiple separate maps for certain points in time. However, this is not an efficient way to show the dynamics of the situation. By contrast, Fraunhofer IOSB's Digital Map Table (DigLT) was designed right from the start to ensure that developments taking place over time are easy to visualize. This relates to both storing data and visualization.

At the same time, changes can be captured, potentially at any time interval desired. That brings huge challenges in terms of data storage: It must be possible to write the data very quickly, as both manual changes in the situation and data from external systems may be contributing factors, and some of those systems supply their inputs very frequently. At the same time, capacity for very fast data retrieval is required in order to visualize the development of the situation dynamically, without any lag.

To ensure that users have intuitive access to the temporal data kept on file, the Digital Map Table features a timeline. This function can be used to set the point in time shown by the table to any time the user wishes. It might be in the past, for instance if the goal is a retrospective assessment of the planning that has taken place to date, or — in the case of position data that are fed into the system on an ongoing basis, for example — to discuss a development after the fact. Or the time for which the table is set can be in the future, which is useful for planning future developments. Additional tools also come into play to simplify use as far as possible. Routing tools have been integrated, for example. This means not all position changes have to be made manually during planning; instead, they are automatically calculated.

In the current version of the DigLT software, temporal visualizations are limited to annotations and sensor data. Going forward, however, advances in technology are opening up the opportunity for dynamic visualization of background data such as aerial views as well, meaning that these are updated more frequently and the dimension of time will need to be factored in for these data as well, in terms of both data storage and visualization.

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Unlike with paper, the Digital Map Table can be used to produce dynamic visualizations of how a situation develops over time and then work intuitively with them using the timeline feature.

Interoperability of unmanned systems: steps toward European standardization

Unmanned systems — whether in the air, on land, or on or under the water — are increasingly becoming a key tool in civilian and military operations. They perform a wide range of tasks, from gathering data to providing services (such as transportation, navigation, and communication) and providing effects (kinematic and non-kinematic). Because of the complexity of the tasks involved, unmanned systems frequently work together with other unmanned systems or with manned systems and human actors. Various aspects must be taken into account here, including steering and control of multiple unmanned systems from a single control station, transmission of data collected during a mission, and the interoperability of data connections.

Unfortunately, manufacturers have tended to rely on their own navigation and control methods, proprietary interfaces for collecting and processing data, and diverse approaches to operation in complex environments together with manned systems. Lack of interoperability between systems results in vendor lock-in and makes life cycle management more difficult.

To remedy these deficits, Fraunhofer IOSB joined with 18 partners from ten other countries in the INTERACT (Interoperability Standards for Unmanned Armed Forces Systems) project to lay the groundwork for a future cross-industry European interoperability standard for unmanned military systems. INTERACT was financed by the European Union as part of the Preparatory Action for Defence Research (PADR) program.

In addition to interoperable interfaces between subsystems and payloads within an unmanned system (intra-system interoperability), the researchers also proposed solutions for standardizing the data connections between individual unmanned systems and between unmanned systems and their control station. Beyond that, they devised proposals for an interoperable control station that can act as a single control center in coordinating the deployment of multiple unmanned systems and enables controlled transfer of unmanned systems to other control stations.

These interoperability solutions and standards have been combined and integrated into an open architecture for unmanned systems. The results were presented in the context of a simulated exercise in which representatives of European armed forces and defense ministries and the European Defence Agency (EDA) participated, among others.

In this way, INTERACT defines the first step toward interoperability across the entire unmanned system life cycle. This is a critical strategic requirement for the competitiveness of the European defense industry and a key prerequisite in European armed forces achieving information and decision superiority over their adversaries.

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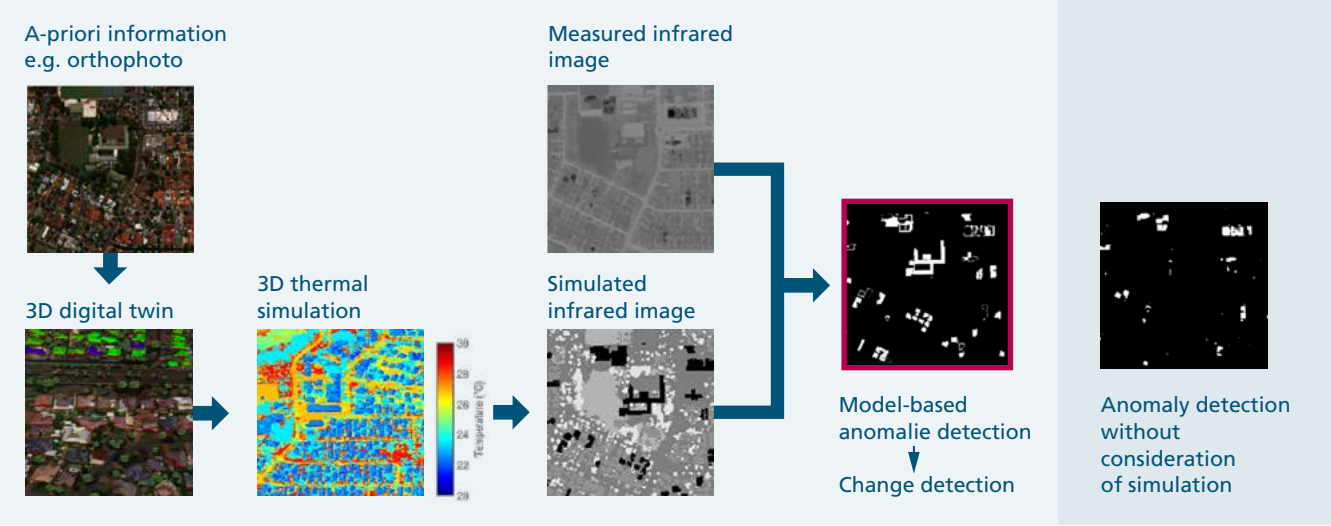
Screenshot of a scenario demonstrated during the simulated exercise.



Schematic representation of simulation-assisted detection of human activity in IR images.

A new IR reconnaissance paradigm: simulation-assisted anomaly detection

Warfare in the 21st century raises new challenges with regard to acquisition, consolidation, and usage of information. With more and more urban battlefields and less distinct frontlines, well-established reconnaissance techniques need to be adapted to new kinds of information stemming from the new environments and conditions. Current developments in AI-based reconnaissance appear promising, but they require huge amounts of data available beforehand, called "training data," and they fuel the development in adapted countermeasures such as camouflage.

To tackle these challenges, we developed a new reconnaissance concept that aims at robustness against camouflage and applicability in urban battlefields. As operability during nighttime is important in reconnaissance, we particularly focus on the thermal infrared spectrum.

The concept's foundation lies in a shift of perspective: Instead of looking for specific objects in data, such as mines or tanks (which might be camouflaged), we generally search for traces of human activity, for example trails of heat on the ground, abandoned firepits, or irregular hot spots in an urban area. To distinguish these, some kind of expected state or background has to be defined, which is where simulation comes into play: To create a digital representation of a real urban area, we build on our expertise in methods and procedures to generate fused source data from 3D data of various characteristics and origins — including 3D data derived photogrammetrically from image and video data, results of laser scans, or conserved geodata from geographic information systems (GIS) — in combination with our expertise in physical modelling of urban heat.

The resulting digital twin of the urban area includes the surface temperature depending on given weather conditions and enables us to render single thermal infrared images. These constitute the simulated, expected state which, in essence, is to be compared to actual images of the area. Deviations between the two are interpreted as human activity of any kind.

Initial tests under the premise of proof-of-concept have confirmed the feasibility of simulation-assisted reconnaissance of human activity. As expected, the results depend on both the reliability of the thermal simulation, i.e., the expected state, and the details of the image comparison approach. To incorporate the power of AI-based techniques, follow-on research is focusing on the generation of synthetic training data.

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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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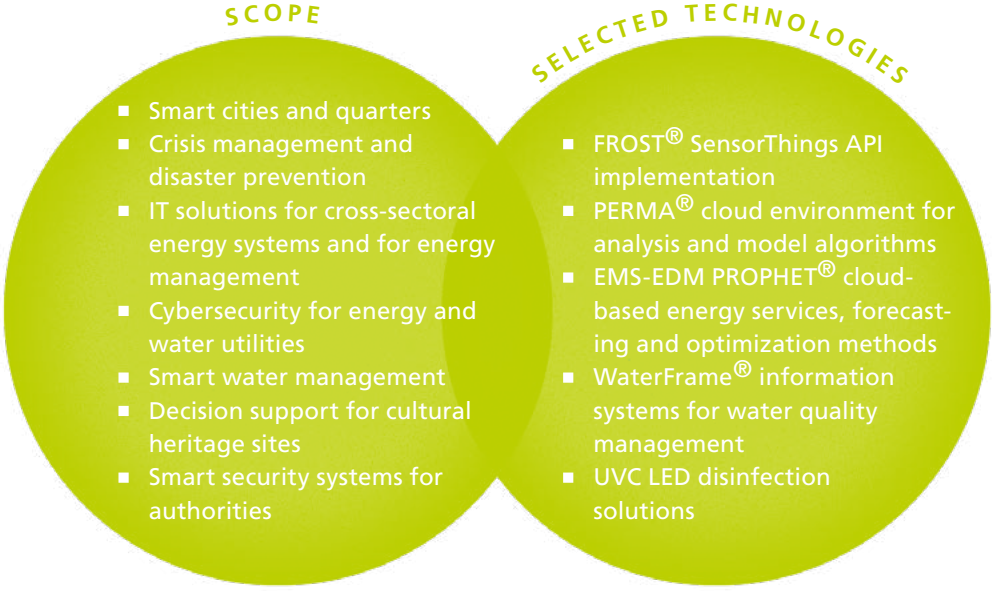
Departments involved

- DIS
- EIS
- ILT
- KES
- MIT
- MRD
- OPT
- SPR
- UWR
- VID



Digital solutions give us more flexibility and agility for managing crises«

From flooding to human-made threats, solutions from IOSB support government agencies and public safety and security organizations at a strategic level

Dr. Moßgraber, the climate crisis, coronavirus, or armed conflicts have made people aware of how vulnerable we are. How can digital technologies help with this?
Jürgen Moßgraber: In many ways! We as business unit see our mission as being at the strategic level. We develop digital tools that support those whose job it is to manage crises, coordinate actions, and ideally identify risks ahead of time and make plans to avert or counter them. You could say we're responsible for software solutions that are as effective as possible for the situation centers and their dialogue with each other. In Baden-Württemberg, for example, that means between the interior ministry, regional and local government, and all the way down to the municipal level.

What solutions do you mean?
We study ways to mitigate the impact of the climate crisis, for example by using AI to help predict disastrous flooding and give people more time to prepare. We also develop coupled simulations for complex scenarios specifically in urban settings to optimize security measures before an emergency occurs. That's something we do at Fraunhofer SIRIOS in Berlin (see p. 10). One key task is situational awareness and assessment. Tools in this area ideally bring together all the available information, visualize it in a clear and easily understood format, and are flexible and user-friendly. Fraunhofer IOSB works continuously to develop and refine two complementary systems for this: the Electronic Situation Dashboard for Civil Protection, called ELD-BS for short, and the Digital Map Table. Both have been in real-world use for years and have proven themselves many times over.

What challenges do you focus on?
We think a lot about how to prepare for the next "black swan" event. One important goal is to maintain flexibility in the face of new and unexpected situations, like the coronavirus pandemic when it first hit. In practice, it can often be difficult to gauge the full extent of a situation fast enough. Take flooding, for example. Will it only affect individual houses, maybe a village or two, or will the whole area be hard hit? The best way to meet both challenges is through interoperable, end-to-end solutions that connect municipal and state authorities with each other and incorporate as many data sources and resources as possible. That's the path we're on in Baden-Württemberg with ELD-BS. But situations typically don't stop at political borders, and there are hardly any comparable systems, let alone compatible ones, in other states in Germany or at the national level or with the Bundeswehr's homeland defense forces. There's tremendous potential for development there.

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PrognoSF aims to precisely predict local flash floods by exploiting all available data sources with AI based algorithms.

Dynamic and precise forecasts for flash floods

Due to climate change, growing urban areas and more and more impermeable surfaces, floods triggered by intense rainfall are becoming more frequent and severe. Although early warning systems have been the subject of research for a long time, predictions, especially for local events, are highly inaccurate. In our in-house PrognoSF project, we tackle this problem with the aim of making disaster prevention and management more effective.

The idea is to combine sensor data on precipitation, water levels, and land use, obtained from remote sensing or local smart city platforms, with high-resolution precipitation forecasts provided by the German National Meteorological Service (DWD). To this end, we connect sensors and existing data platforms with a modern sensor data management system and AI modules, relying heavily on open standards. In particular, we use our own open-source implementation of the OGC SensorThings API (aka the FROST® server) with PERMA allowing for easy integration of AI calculation modules via Docker Containers, and our WebGenesis® decision support web platform.

Our development activities in PrognoSF include designing specific sensor stations and connecting them to smart city platforms via LoRaWAN, as well as developing various AI-based modules with the aim of enabling faster and more accurate predictions for improved early warning. The modules, the first versions of which have been implemented, include a local precipitation forecast, image processing that extracts current land use from satellite imagery, and water level and discharge forecasting based on historical data, real-time sensor readings, and weather.

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

An intelligent cross-sectoral approach to managing energy use in city districts

With an eye to the current energy crisis and as a result of significant increases in the price of natural gas and electricity it has caused, it is imperative to create alternatives to fossil fuels, but there is also a need to develop innovative new ways of managing sustainable energy systems. City districts such as those in Bochum's Weitmar area offer a wealth of potential in this regard. The ODH@Bochum-Weitmar research project considered new business models and developed and tested technologies, methods, and tools to highlight possible ways of supplying energy to districts with both environmental and economic efficiency.

The joint research project was successfully concluded in March 2023. It served as a prime example showing that efficient handling of energy at the district level is possible. Sub-modules developed as part of the project included an integral district planning system, a self-learning energy management system (SEMS), a digital market platform (DMP), and a middleware data platform. The potential existing in this area became clear during the implementation and test operation, but so did the challenges remaining as we move toward broad-based real-world uptake in city districts, especially with an eye to overall legal and regulatory conditions. Participants included Fraunhofer IOSB-AST, whose research focus was on developing the SEMS for efficient and optimized district operation, and Fraunhofer IOSB-INA, which concentrated on creating the ICT ecosystem needed to integrate the various components into a single overall system.

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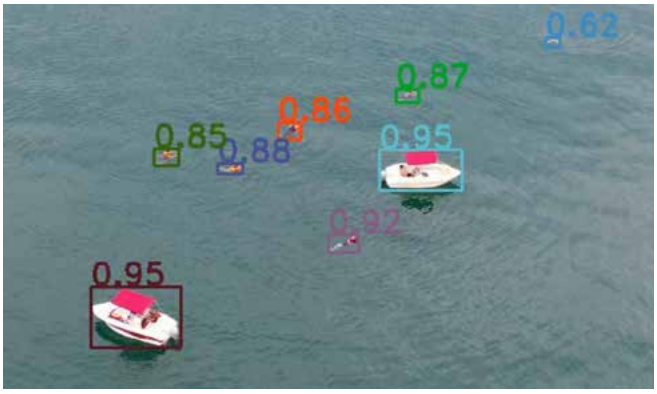

Classification results of maritime objects.

Studying UV radiation sources in the incubator.

Maritime object classification

Within image exploitation, one of our core competences, one traditional focus of our research is the detection of persons and the evaluation of their actions, which has multiple applications in the field of public security. Other aspects include the classification of objects in various environments, and the use of computer vision in the control of unmanned systems such as unmanned aerial vehicles (UAV) and unmanned surface vehicles (USV).

In early 2024, a Fraunhofer IOSB team participated in an international competition at the 2nd Workshop on Maritime Computer Vision (MaCVi) and came in a close second in the challenge "UAV-based Multi-Object Tracking with Reidentification". The challenge focused on the detection, tracking and classification of swimmers, boats, and other objects in open water. There, waves, sun reflections and the fast movement of the airborne video camera complicate things for computer vision algorithms. However, our team was able to complete all tasks, including long-term tracking of objects despite their occasional partial occlusion.

These results pave the way for the development of assistance systems for search and rescue missions, such as when ship passengers fall overboard or during flood disasters.

Development and investigation of LED-based UVC radiation sources for incubators

Premature birth is often associated with significant health risks to the newborn. Premature babies do not yet have a functioning immune system, and the skin and gut microbiomes have not yet fully formed, either, so they do not serve their protective functions. This means premature infants need to be protected from harmful pathogens such as those found in hospital settings, even with the best possible hygiene practices in place. Special incubators achieve this to a very high degree with air filtration and other measures. Still, studies have shown that harmful pathogens can enter the incubator and come into contact with the newborn unintentionally during the process of caring for these babies.

To lower the microbial count in the incubator and thus raise the survival rate for premature infants, we have developed a UVC radiation source for air and surface disinfection for incubators. It is regularly used when the infant is taken out of the incubator and placed skin to skin on a parent's chest as part of the "kangaroo" method of care. Meanwhile, the incubator is effectively disinfected from the inside with UVC radiation. A double-blind study is currently being conducted to investigate the device's clinical benefits.

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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. On the other hand, we develop IT systems that process and analyze these signals in real time and, on this basis, provide 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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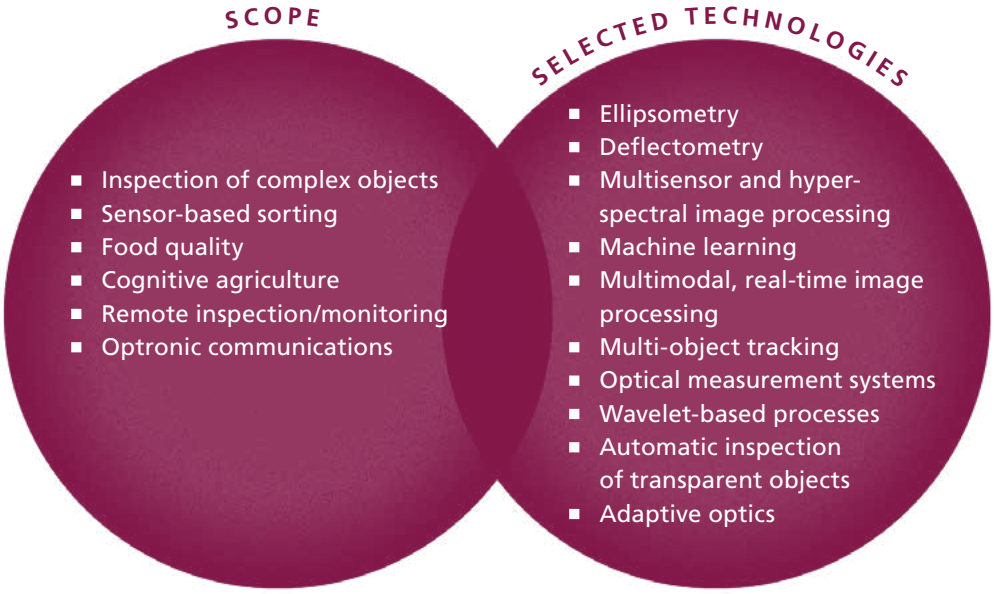
Departments involved

- MRD
- OPT
- SIG
- SPR
- SZA



Simulated defects open the door to AI applications«

How synthetic image generation can solve the "chicken or egg" problem for AI used in inspection

Prof. Längle, AI is causing a lot of disruption. Does that include your business unit?
Thomas Längle: Machine learning (ML) has played a big role in computer vision for quite some time now. It has direct applications for us in fields such as remote sensing — so, in analyzing and interpreting aerial images — and in sorting bulk goods. One exciting trend we're seeing right now is in the area of inspecting surfaces and complex objects, where the advances in detecting and classifying defects that we might expect from ML approaches have often been stymied by lack of data. To train the AI models, they would need to be fed a large number of examples of good products, but also be supplied with precisely labeled bad ones. There just aren't enough of those, if any at all. So we've turned the focus of our efforts on synthetic image generation.

You're planning to generate the data to train the AI with AI?
Well, we already do have experience with ML approaches such as generative adversarial networks, variational autoencoders, and diffusion models for generating new versions of bad examples on the basis of existing images. But primarily, we're working with simulations. The idea is to simulate the entire testing and inspection environment — specimen geometry, material properties, lighting, sensor technology — to produce images that are synthetic, but still sufficiently realistic. And then we can take data on defects that we have gathered in the past to add virtual errors as well and vary them in a number of ways. With a scratch, for example, we can cycle through different lengths, depths, and shapes. On this basis, we can then calculate the images that the analysis AI would ultimately face in the chosen inspection setup.

What are the advantages of this simulative approach?
It might help us solve the "chicken or egg" problem. ML-based reproduction of images of defects requires that there be at least some images already on hand, so it still depends on the quantity and quality of the input data. We can also build in any kind of error we want, and, of course, the synthetic images created in this way are always labeled perfectly. That's because we know which defects we simulated and where. We can also change other relevant parameters. In real life, defects aren't the only things that vary. There's a certain amount of spread to a specimen's position and dimensions, the lighting varies somewhat, etc. Ultimately, the simulation gives us a digital twin of the inspection setup — which we can also vary virtually. So we can test and optimize the entire system and draw conclusions about how it will perform before translating it into hardware.

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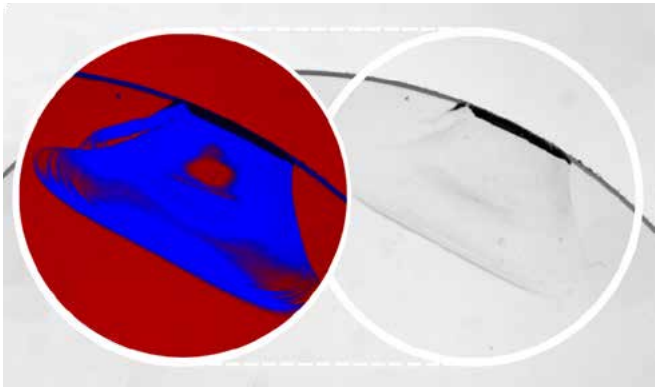

The advantage of light field illumination (left) in direct comparison to traditional bright field illumination of the same specimen.

Light field technologies unlock rapid prototyping of inspection solutions

Increasing variety, shorter product lifecycles, and smaller unit quantities pose a new challenge for automated visual inspection. Component designs change in just a few years or months, and to keep up, testing and inspection systems should be quickly adaptable — with as little hardware needed as possible — in order to handle previously unknown specimen shapes and configurations.

One initial crucial improvement for greater versatility is the introduction of light sources based on light fields, which can be used to set the direction distribution of the beams of light flexibly via software, creating a four-dimensional light field. We can tailor the field automatically to the relevant component. This means that the light field projected onto or into the individual specimen is optimized such that relevant structures can be detected with maximum contrast. The lighting is adjusted adaptively to the problem.

The illumination pattern is thus adjustable "inline" in just a short time, without any changes to the hardware. In particular, it is possible to implement and optimize systems automatically as part of rapid prototyping without necessitating any mechanical adjustments to the components. This considerably reduces the amount of time and work required and provides a key economic benefit compared to traditional systems.

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Laser Doppler vibrometer for taking measurements on moving objects.

Remote vibration measurement of wind turbine blades

Fraunhofer IOSB is developing a laser Doppler vibrometer system for distant vibration measurement on rotor blades of wind turbines in live operation.

Based on high-frequency speed measurement, the laser Doppler vibrometer (LDV) that has been built can use the Doppler shift in laser light over a distance of several hundred meters to record vibrations on the surface of an object. At the same time, an image processing system analyzes the rotational movement of the turbine rotor in a camera image. The LDV is installed on a pan/tilt platform. This allows the computer to track the rotor's movement with the laser measuring spot for the necessary period and stabilize it at a desired measuring point. The challenge in analyzing and interpreting the data consists in separating the microscopic vibration movements from the rotor's own macroscopic movements.

Built into a car trailer, the measuring system can be relocated quickly and used for routine vibration measurements in research projects. The vibration spectra measured using LDV to date have shown frequency peaks that can also be associated with known vibration phenomena found in wind turbines. Comparative measurements on a research turbine whose rotor blades were equipped with vibration sensors by the Fraunhofer Institute for Wind Energy Systems IWES have confirmed the reliability of this measurement method.

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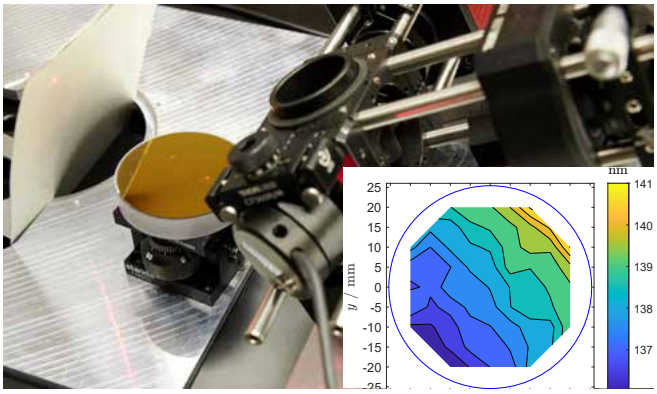

Measurement setup and result for film thicknesses of a concave mirror.

Fast-switching pneumatic valves remove plant particles contaminated with PAs.

Retroreflex ellipsometry for non-planar surfaces

Conventional ellipsometry is only suitable for planar or near-planar surfaces. Measurement of nonplanar surfaces involves time-consuming alignment of the sample and only specific sampling points are measured. This constraint limits the use of ellipsometry in industry. However, quality monitoring or characterization of nonplanar surfaces is required for different applications, such as the uniformity of metallic coatings and functional coatings on lenses (e.g., anti-reflection coatings, self-cleaning coatings). We propose a holistic approach to resolve this problem: retroreflex ellipsometry.

Retroreflex ellipsometry uses a retroreflective sheet that returns a light beam from the sample back along the same beam path. The polarization properties of the retroreflector are the same as those of an ideal mirror, but within an angular range of ±30°. The alignment condition for the sample and the detector is automatically fulfilled, and thus retroreflex ellipsometry can be used to measure nonplanar surfaces without the need for precise manual adjustment in order to achieve angular tolerances of less than 0.5°.

The retroreflex ellipsometer we developed is capable of determining optical properties or film thicknesses of nonplanar surfaces (e.g., spherical mirror) quickly and with high accuracy. Reflectance and ellipsometric data can be measured without apriori information about materials and angle of incidence. This makes retroreflex ellipsometry an ideal tool for differently shaped surfaces as well as for inline and in situ quality control systems.

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Detection and removal of weeds containing pyrrolizidine alkaloids from harvested crops

Pyrrolizidine alkaloids (PAs) are secondary metabolites produced by plants to protect against natural enemies. When weeds containing PAs are harvested along with other crops, they can get into foods (lettuce and other leafy greens, herbs, teas) or plant-based drugs. This kind of contamination poses a potential health risk due to the liver toxicity and genotoxicity of these compounds. Just a few plants per hectare can be enough to make the entire harvest commercially unviable. The only way to fight weeds containing PAs in the field is generally mechanically, which is costly in terms of personnel. Increasingly, there is no way for growers to do this economically. Imported dried goods often contain higher than approved levels of PAs as well.

To remove plant parts containing PAs from the product after the fact, Fraunhofer IOSB has developed a prototype of a sorting system as part of a joint research project funded by the German Federal Ministry of Food and Agriculture (BMEL) and Fachagentur für Nachwachsende Rohstoffe e. V. (FNR). The automated system detects the toxic PA weeds based on hyperspectral imaging sensors in the short-wave infrared range. An AI-based classification model was trained using hyperspectral data. The deep neural network, which was optimized for real-time operation, achieved detection rates of over 90 %.

An automated sorting system was optimized for sorting small, dried plant particles with an eye to material handling and other sorting parameters. This makes it possible to efficiently clean heavily contaminated plant streams through multiple sorting passes: Just three passes reduce PA content by more than 99 %.

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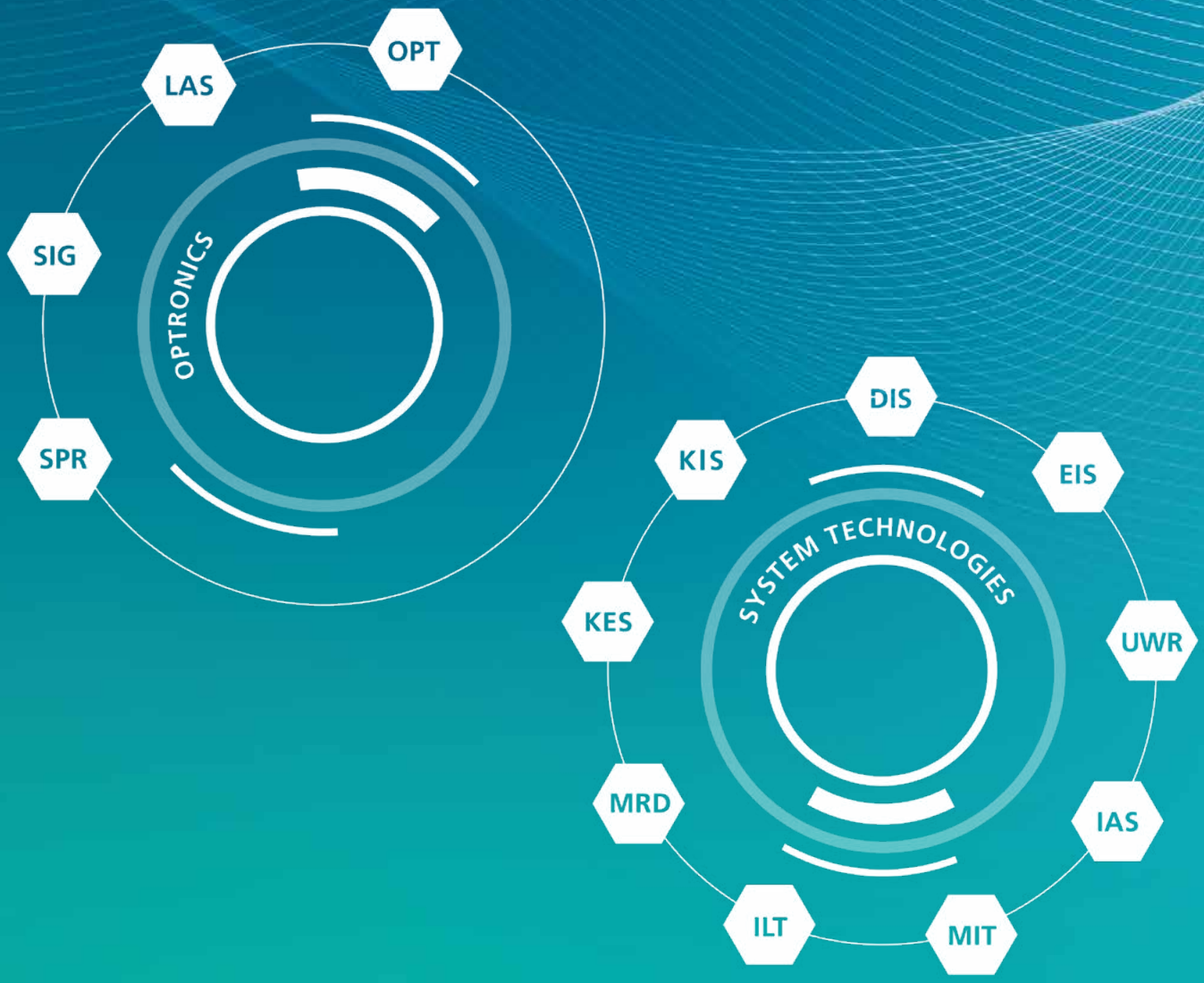
Departments

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 and non-linear sources in the NIR, SWIR, MWIR, and LWIR spectral ranges, 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
Active fibers

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Research areas and expertise

Drawing on our expertise 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 2-2.2 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 lasers 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-pulse-energy and non-linear converters and to develop new or optimized components. Our crystal growth activities focus on enhancing laser and NLO crystals for optimum performance.

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., for 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 the Bundeswehr (German Armed Forces), industry, and internally, where they are used to study optronic and photonic applications, such as evaluating passive and active optronic sensors and laser protection. We also investigate optical damage thresholds at SWIR and MWIR wavelengths on optical components (optics, laser, and non-linear crystals) according to R-on-1 or S-on-1 (ISO standard) protocols. Laser damage (LIDT) measurements and power handling measurements using our sources 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 including diodes and fiber lasers in the NIR and SWIR range, a large selection of active laser materials such as 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. In addition to our state-of-the-art equipment, we employ some of the state-of-the-art and sometimes very rare electro-optic metrology devices and equipment for manufacturing specific fiber-optic and optical components.

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

Expansion to active fiber research for security of supply
In April 2022, the city of Oberkochen (Germany) granted the Laser Technology department 10 million euros in funding for research and development of active silica fibers. The definition of the technical and scientific infrastructure has been finalized, and equipment procurement is underway. The commissioning of the equipment and the start of research activities coincide with the completion of construction work on the new Hensoldt Optronics building in Oberkochen, where Fraunhofer IOSB will be renting around 500 m² of cleanroom space. Recruitment has begun.

In June 2023, the city of Oberkochen renewed its confidence in the Fraunhofer IOSB laser strategy and granted a second 10 million euros in funding for the creation of an additional research laboratory, this time dedicated to fluoride fibers. These fibers enable the research and development of new MWIR lasers and non-linear sources.

An important facet of the research is focused on fiber optic components needed for integrated lasers and systems; those available on the market often being limited in security of supply or unreliable for the energy or power ranges addressed by Fraunhofer IOSB.

High-power fiber lasers and environmentally hardened laser designs
The demonstration of a monolithic (all-fiber) continuous wave Tm:silica fiber amplifier with a narrow line width and 937 W of output power with a nearly diffraction limited beam quality of M^2 ~ 1.2 takes the laboratory to the very top of international research in 2 µm fiber lasers, the world record being 1.1 kW.

Moreover, this IOSB fiber laser is ahead of all comparable designs in terms of compactness and simplicity and achieves a very high differential efficiency of 58 %, which is important for thermal management and integration aspects. Ongoing research into coherent combination of multiple sources of this type is targeting power scaling for high-energy laser (HEL) applications.

Ruggedized thulium fiber laser for military applications.

To address specific military needs in ruggedized laser designs, the LAS department has also put a focus on specific realizations of fiber and solid-state lasers for extended operating temperature ranges or reduced alignment sensitivity. Therefore, passively-cooled Tm:fiber lasers with ultra-low thermal sensitivity or beam-quality-preserving highly efficient Ho:YAG amplifiers with average output powers above 120 W have been designed and successfully implemented.

Fiber spool, fiber drop, and fiber preform.

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

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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 expertise

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. We develop prototypes for new imaging paradigms such as quantum ghost imaging and compressed sensing. Moreover, we conduct research on high-energy lasers (HEL) using simulations and experiments. Furthermore, the department uses analytical and computational approaches to model sensors and the imaging process, including 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

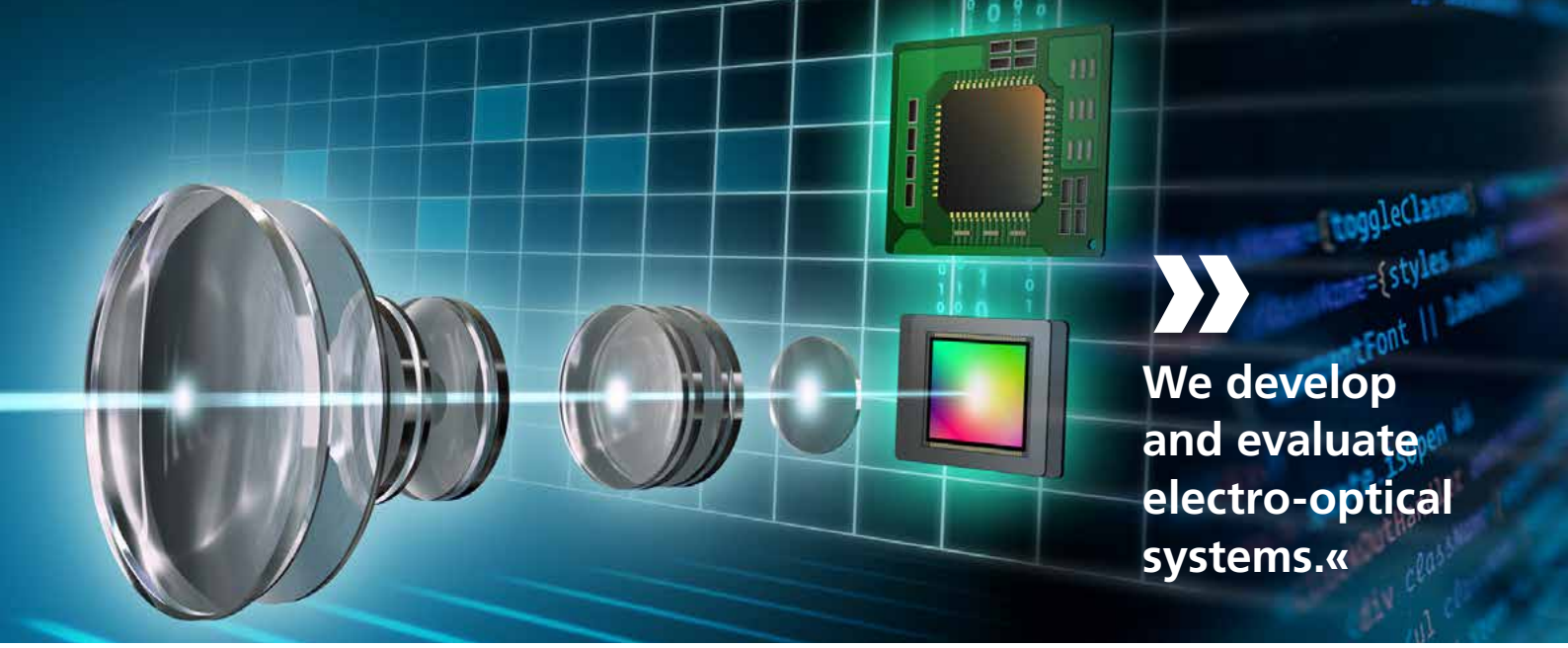
Our TRM4 software can calculate the performance of scanning and staring thermal imagers as well as cameras for visible to SWIR wavelengths. TRM4 is adapted to changing technology and applications on an ongoing basis.

Our OSIS simulation tool simulates sensor images for user-defined imaging systems and scenes. Convolutional neural networks (CNN) are used for evaluating the simulated images. Safety requirements for (high-energy) lasers represent a unique challenge. 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), the capability to actively monitor the environment without being detected, and to capture images through a harsh atmosphere such as smoke.

Infrastructure and lab facilities

We have 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 countermeasures (OCM). Our equipment includes a fast, high-precision IR-scene projector with 1024x1024 pixels for evaluating calibrated cameras and algorithms, and test stations for performance characterization of thermal imagers and night vision devices.



»We develop and evaluate electro-optical systems.«

Highlight topics

Image simulation for optronic systems
The Optronic System Imaging Simulator (OSIS) is a software tool used for the image simulation of camera-related image degradation effects. These include optical diffraction, aberration, sensor sampling, temporal and fixed pattern noise, digital signal processing, and interpolation on screen. For convenience, applied filter modules for image degradations are controlled by camera specifications within the TRM4 [1] software, which is the German reference model for range performance assessment developed by Fraunhofer IOSB. OSIS is provided as a dynamic link library, which enables easy integration into other third-party software. Parts of the OSIS software's capability are integrated in the ECOMOS-2 project [2] of the European Defense Agency. ECOMOS-2 is a novel approach for electro-optical system performance assessment that will enable evaluation of the effect of advanced digital signal processing algorithms on imager performance.

For investigating individual camera properties, users can retrieve simulated imagery at different stages of the image chain. Furthermore, there is a plug-in interface for advanced digital signal processing. It enables the application of algorithms for image and video signal processing developed by the user, such as contrast and edge enhancement, digital image stabilization, and noise reduction.

Synthetic image degradation by OSIS opens up a wide range of possibilities for data augmentation on small datasets of input scene imagery, which can be crucial for robust AI applications such as image enhancement or automatic and aided target recognition.

3D remote sensing with structured light
Imaging under adverse conditions, i.e., through fog, smoke or fire, demands imaging techniques capable of returning high-resolution images through scattering and turbulent media. Active imaging systems that use their own light source for illumination are ideally suited for this task. A key advantage of such systems is direct control over the light source, which allows the utilization of time-of-flight (ToF) information of light to suppress unwanted background noise and obtain depth resolution.

The development of focal plane arrays has advanced significantly, featuring high counts of pixels with time resolution. However, this progress is limited by very high data transfer rates of highly resolved 3D data that are in the multi-gigabyte per second range. As a result, data compression has become a crucial tool to transfer key information close to real time.

By using structured light for illumination, it is possible to compress data even before detection. Using compressed sensing methods, image data can be reduced by an order of magnitude without compromising visual quality and depth precision. Limited data bandwidths can thus be used most efficiently for real-time imaging of dynamic scenes.

Moreover, structured light offers the benefit of requiring only a single-element detector, allowing the use of high-end technology with low noise and time-resolution capabilities across any spectral range. This eliminates the need for developing new camera models featuring arrays of millions of identical, less specified individual pixels, an outcome often necessitated by array implementation.

Compressive sensing image of Fremersberg tower near Baden-Baden, Germany, at a distance of 26.5 km.

Links to OSIS:

[1] https://s.fhg.de/trm4
[2] www.ecomos.org

SIG | Signatorics

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

Research areas and expertise

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 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 covers 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 are based on our own ground, sea, and air-based sensor systems and measurement methods. Our adaptive optics test stations allow for the modelling and correction of atmospheric and underwater turbulence. In our underwater turbulence laboratory, we conduct experiments with exotic states of light propagating in water, which has applications in covert underwater communications. 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.

We use relevant programming environments, software development tools, and standard design tools for CAD and optical design (Zemax, for example). For numerical simulations, used both to supplement experiments and to develop parametric approaches, we utilize leading-edge software including atmospheric transmission codes such as Modtran and Matisse, EO/IR scenario simulation programs such as TAItherm, ShipIR/NTCS and Cameosim, and multi-physics environments such as Comsol and Ansys.

SIG

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Research groups

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

iosb.fraunhofer.de/SIG

Free-space optical communication lab with view of Ettlingen.

Highlight topics

Free-space optical communications
Based on our experience in laser beam propagation through turbulence, we design, implement, and test free-space, laser-based telecommunications concepts. Our laser communications laboratory (LCL) has two free-space paths that either originate or terminate there. The first path is an 800-meter double-pass link to a retroreflector and back to the receiver. Telecommunications experiments have been performed over this path, since 2018. Data rates have continuously increased: from 5 Gbit/s in 2020 to 12.5 Gbit/s as of 2023. As a reference, top-of-the-range home Internet delivered by fiber optic cable in Germany is currently limited at 1 Gbit/s.

One of our approaches is called "coherent modulation". While in traditional on/off keying only the laser's intensity varies, we independently modulate the amplitude and phase of the signal. As a result, several bits can be sent at once with a single laser "pulse". With polarization diversity, an additional data channel could be opened. We currently transmit four bits per symbol. At the same time, we investigate how to mitigate the effects of atmospheric turbulence on the quality of the transmitted data. With the techniques implemented in the LCL, we have achieved error-free transmission over 95 % of the time. The goal is to increase this percentage to 99 % in the coming years to meet industry requirements.

The second link to be commissioned is a single-pass laser propagation path spanning 7.2 km from a Karlsruhe Institute of Technology building to the LCL. This will be a fixed facility dedicated to research on the effects of atmospheric turbulence on propagation of Gaussian and other types of laser beams.

Shipborne IR signature measurements with the I3R system
Field experiments to determine an IR object signature become necessary when measurements in the laboratory are not possible or not sufficient; for example, to capture larger objects under real conditions in order to obtain comparative data sets for validation of IR scene simulations. This type of measurement requires accurate characterization of sensor systems, target, and environment, to ensure a high-quality result. This is a challenge at sea, particularly when investigating maritime objects from a ship.

Our integrated imaging IR (I3R) measurement system makes a multi-spectral investigation at sea a solvable problem. It is equipped with two sensitive quantum detectors in the LWIR and MWIR spectral range, which are supplemented by sensor systems for the visual and short-wave IR (SWIR) spectrum. Encased in robust housings and mounted on a stabilized pan/tilt unit (PTU), they can withstand even adverse conditions at sea. An environmental measuring station and systems for position and attitude determination are also connected. All data from the subsystems is fed into the system's central control unit. This provides the user with an integrated view of all relevant data and allows them to control the system. The system supports the user by displaying deviations in the measurement process and by automatically tracking the target object. It gives the user the freedom to precisely observe and coordinate the measurement, which further increases the quality, efficiency, and probability of success of the measurement.

Main sensor systems of the I3R measuring system aboard a small ship during sea trial.

SPR | Visual Inspection Systems

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

SPR

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Research groups

Sensor-based sorting
Computational Imaging
Spectral Imaging

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Research areas and expertise

Our work revolves around using optronic sensors and machine vision for characterizing and inspecting a variety of materials and objects. We work with various types of high-resolution line-scan cameras (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 hardware acceleration and image exploitation algorithms. These are essential in view of the high throughput rates of the inspections and the need to build reference databases. Our solutions are currently in use in a large number of factories where they perform tasks such as quality control.

Applications and products

We develop sensor-based sorting systems. 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. These solutions are used in industrial settings around the world.

In addition to industrial quality control and circular economy applications, we increasingly utilize hyperspectral imaging in smart agriculture and along the food chain.

Infrastructure and lab facilities

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 entire wavelength range from UV to MWIR, experimental systems for sensor-based sorting (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

Automated quality assessment of fruit and vegetables
According to the United Nations, around 30 % of food produced worldwide ends up as waste. This makes food waste one of the biggest challenges of our time. The high sector inefficiency can be partly explained by the short shelf life and vulnerability of fruit and vegetables, as well as deviations from retail standards due to varying appearance and color. This makes it necessary to perform continuous quality

controls of fresh produce – a process that is usually time-consuming and destructive.

In a collaboration with Fraunhofer IVV and IZFP, we developed a multisensory scanner for non-destructive quality detection of fresh food. A cooperation with a fruit and vegetable wholesaler made it possible to adapt the scanner directly to the requirements in a goods receipt. By viewing entire crates at once, a time-saving, workflow-integrated process was established.

The multimodal system incorporates various sensors that enable fast data assessment, including a multispectral near-infrared (NIR) camera. Due to the tendency of plant tissue to reflect light in the near-infrared range, certain properties become more visible with NIR imaging. Equipped with various sensors, the scanner can not only extend the range of measurable parameters, but information is also standardized and comparable over time since the scanner captures data under constant conditions. All of this happens with just one touch of a button.

Within the wholesale trade partnership, the scanner was used to acquire real-world data. The dataset serves to train machine learning models, enabling the integrated data analysis to be flexible and data driven. This is essential in addressing the challenges posed by the high variability in fruit and vegetable characteristics, which are difficult to detect using traditional methods.

Detecting and removing hazardous materials from construction and demolition waste

Manufacturing of new construction materials is responsible for about 11 % of global greenhouse gas emissions. One climate-friendlier way of producing construction materials is to recycle construction debris from demolished structures. Producing high-quality recycling products generally requires that the material is recovered as pure as possible, with impurities sorted out. In the past, we worked with Fraunhofer IBP to develop sensor-based sorting solutions to fill this need.

In addition to needing materials to be sorted properly, harmful substances that could be contained in construction debris present a serious problem. These kinds of materials need to be detected, separated, and handled individually, all at an early stage of the process. There are also legal limits to observe in many cases.

State-of-the-art camera technology is used to acquire image data in the hyperspectral imaging lab for training AI models.

One example is asbestos, which was commonly used in older buildings and other structures for insulation, fire prevention, and stabilization. If asbestos fibers in the air enter the human lungs, physical harm can result. With this in mind, we are developing a nondestructive, low-cost method of detecting asbestos using imaging sensors as part of the DIANA project. This makes it possible to detect asbestos fibers early on and separate them from uncontaminated material.

Hazardous materials also play a key role in the recycling of road surfacing. Tar was used as a binder in Germany up until the 1980s, but it contains toxic hydrocarbon compounds. In the InnoTeer project, we are working on a method of using a hyperspectral imaging camera in the mid-infrared range to detect binders that contain tar. This will make it possible to recycle non-hazardous road surfacing materials containing bitumen.

The AI-based analysis of standard fruit crates is performed directly on the multisensory scanner.

KES | Cognitive Energy Systems

The Cognitive Energy Systems department develops pioneering technologies in the field of energy systems engineering with a focus on 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

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Research areas and expertise

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, we are ideally positioned to master the challenges of the energy transition, particularly in the electricity, gas, and heat supply sectors. This transformation, which is increasingly being driven by energy generation from renewable sources, is based on new integrated approaches to linking the electricity, heating, gas, production, and e-mobility sectors. An essential key to the success of the transformation is the digitalization of energy supply systems, and here, the IOSB, in form of the department KES can make significant contributions to this with our expertise and technical solutions. Additionally, we offer cybersecurity services for the energy and water supply sectors, which are becoming increasingly important in the course of the digitalization of energy and water supply systems.

Applications, products, and services

For the benefit of our customers, we develop and test novel and customized methods, solutions, and services in the areas of energy forecasting, energy usage optimization, simulation, and operational management of electricity, gas, and heat supply systems as well as cross-sectoral energy systems. Numerous energy suppliers and energy service providers in Germany use solutions from our EMS-EDM PROPHET® platform for efficient automated processing of a wide range of energy management and energy system processes, including forecasting energy demand, managing balancing groups, power plant scheduling, optimal operation of sector-coupled energy systems, or for market communication. In partnership with the Fraunhofer Academy, we successfully offer training courses in energy data analysis and cybersecurity. We also use our scientific expertise to support our spin-off AMPEERS ENERGY GmbH in the development of digital solutions for the decarbonization of building portfolios, for tenant electricity solutions and, going forward, for district energy management as well.

Infrastructure and lab facilities

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

Highlight topics

In 2023, we successfully applied for three major energy research projects together with other partners: “BiFlex Industries” will help tap the energy flexibility potential of e-vehicles for industrial companies, “LI-SA” will advance the secure operation of electricity grids with low inertia, and in the “energy

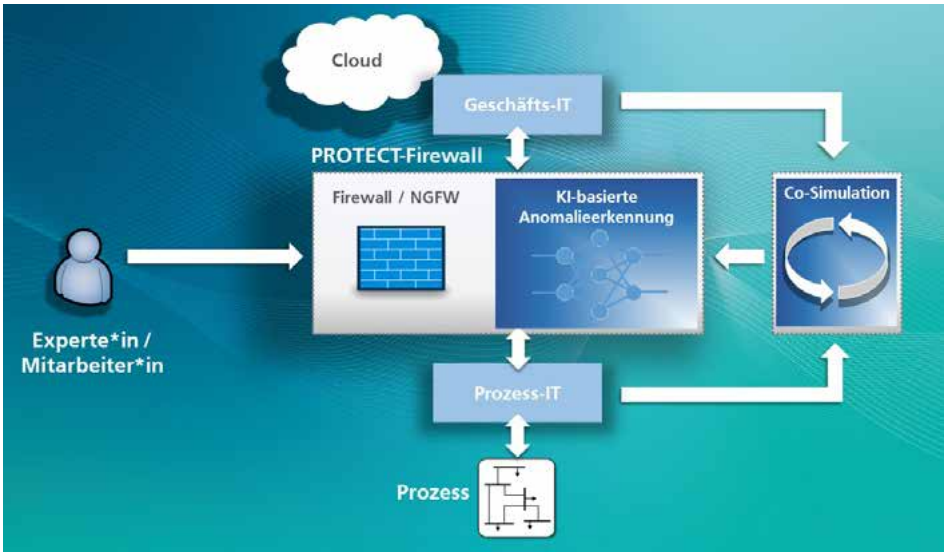
data-X" project, we will develop and test a data ecosystem for the sustainable, secure, and sovereign use of data in the energy sector. We are also involved in the Thuringian joint project "ZO.RRO 2 — Zero Carbon Cross Energy System for Glass Industry". The research projects are funded by the German Federal Ministry for Economic Affairs and Climate Action.

Self-learning AI firewalls for energy supply infrastructures

In the PROTECT project, we are developing a learning and testing system to build and implement a self-learning AI firewall for energy suppliers: We expand traditional rule-based firewall systems with AI-based anomaly detection methods to defend against IT attacks in the commercial IT domain as well as in the process IT domain. The focus is on the (semi-)automated detection of manipulations in network traces to assess the criticality of anomalies in terms of their potential negative impact on essential system structures or components (e.g., network assets, IT components, and communication paths). To this end, we develop an agent-based network simulation in GNS3 to model business services, including mail, web and metering activities, using stochastic working profiles. A coordinated attack simulation framework will be integrated to model multi-stage cyberattacks and create dedicated training and test datasets. The transparent attack detection system is realized with a transformer deep learning architecture and an innovative explanation algorithm in order to identify the most relevant network packets and packet information with a given network traffic sequence.

EU project: Next level Quantum information processing for Science and Technology

The vision of the NeQST (next level quantum information processing for science and technology) project, funded by the European Union, is to leverage recent advances in the control of qudits (multi-dimensional quantum information carriers) in order to generate foundational breakthroughs throughout the entire value chain of quantum computing. These include an experimentally tested qudit platform based on trapped ions, validated automated design tools, tailored certification



Basic concept of agent-based network simulation and transparent attack detection.

methods, and demonstrated feasibility of practical applications. The emphasis is on two use cases of great interest for academia and industry: quantum simulation of lattice gauge theories and quantum optimization for the energy domain, respectively. We, the IOSB Quantum computing experts located in Görlitz, focus on the latter, particularly on optimizing the charging schedule of electric vehicles (EVs).

Optimized bidirectional EV charging, i.e., optimized charging and discharging of the batteries of large numbers of EVs, provides a great opportunity to address two of the challenges arising from the transformation of the energy system: the integration of the growing number of EVs and the rising share of renewable energy. Both cause a sizeable increase in the load of the electricity grid as well as greater uncertainty and variability in electricity production and consumption. To address these challenges, we develop novel quantum algorithms and technical approaches for distributed operations with locally optimized charging including uncertainties.

Quantum optimization with focus on optimizing the charging schedule of electric vehicles (EVs).

KIS | Cognitive Industrial Systems

The Cognitive Industrial Systems department develops intelligent components and processes for flexible and resource-efficient production. This includes the use of AI and machine learning to evaluate large amounts of data in production and new processes for intelligent and flexible automation technology.

Research areas and expertise

Our research focuses on data-driven optimization of production, AI engineering — especially AI in the context of systems engineering, adaptive factory automation, and industrial communication via OPC UA. Located in the Karlsruhe Research Factory, we bridge the gap between cutting-edge research on basic technologies and development of application-oriented solutions. Together with our industrial partners, we develop AI technology and implement it in long-term operations extending beyond the prototype. On the academic side, our work includes being part of the German Research Foundation (DFG) research group 5339, which is dedicated to developing an "AI-based methodology for the rapid upgrading of immature production processes," and a member of the DFG collaborative research center 1574, "Circular factory for the perpetual product".

Applications and products

Within the scope of the Fraunhofer lighthouse project "Machine Learning for Production (ML4P)" and the Competence Center Karlsruhe for AI Systems Engineering (CC-KING), we developed a thorough methodology for the development, deployment, and maintenance of AI-based components in complex systems such as production plants. This resulted in PAISE®, the Process Model for AI Systems Engineering, which we now successfully use in industrial applications.

Our SWAP-IT architecture, also resulting from a Fraunhofer lighthouse project, provides the architecture for a flexible manufacturing infrastructure consisting of adaptive cyber-physical systems. The lightweight and open-source implementation of OPC UA, open62541, which we primarily developed and maintain, has been in long-term practical use by many industrial users.

Infrastructure and lab facilities

The KIS department is situated at the Karlsruhe Research Factory. This allows us to set up, operate, and optimize industrial processes at scale. The Karlsruhe Research Factory also has its own data center, which provides sufficient storage and computing capacity for applying AI-based methods on site. This is important for low-latency applications and for sensitive data that should not leave the premises.

Highlight topics

AI for resource efficiency in industry
We use AI-based methods to improve the resource efficiency of industrial processes — saving money and saving the planet. For this purpose, we use data-driven learning methods to model complex and high-dimensional relations in the observed processes. The resultant model is used for prediction and runtime decision-making, either with the assistance of a human operator or fully autonomously.

KIS

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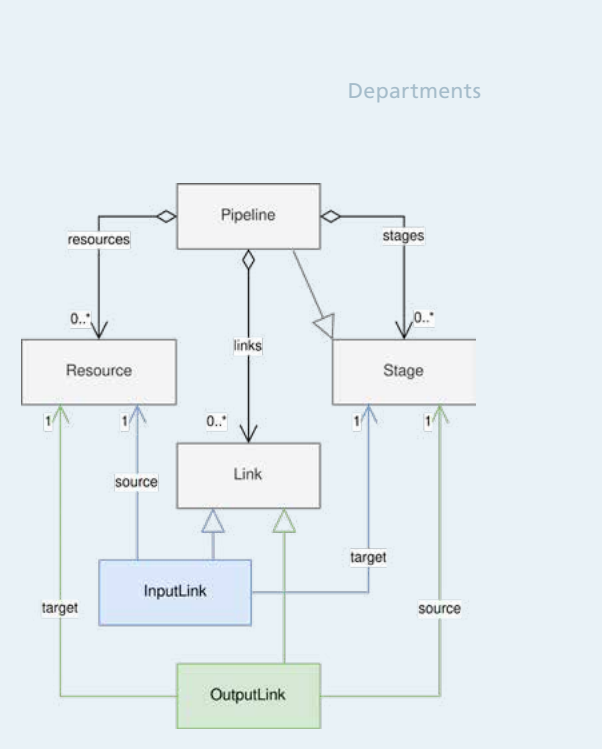
Research groups

Intelligent cyber-physical systems
Adaptive production systems

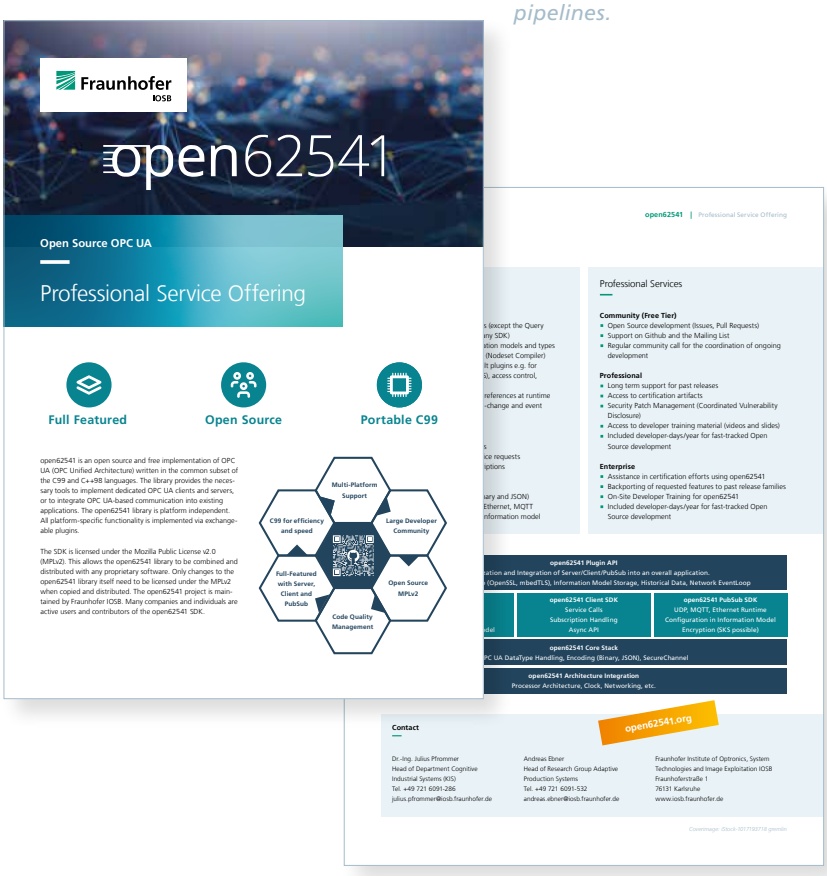
iosb.fraunhofer.de/KIS



PipesAI framework for modeling and implementing AI data pipelines.

Drift detection and long-term productive use of AI components

In collaboration with our industrial partners, we not only validate the use of AI methods in prototypes, but also turn them into industrialized applications for long-term productive use. This experience led to the development of our PipesAI tool suite which is a lightweight framework to structure and build AI training pipelines with the aim to consistently track changes intermediate results. Furthermore, our AutoDrift package empowers users to detect drifts during long-term operations of AI and automatically take appropriatemeasures for model adaption.



open62541 OPC UA

open62541 is a fully featured, open-source, free implementation of OPC UA (OPC Unified Architecture). It is written in the C language, making the software extremely resource efficient and suitable for all types of hardware, including small embedded systems. The library provides the necessary tools to implement dedicated OPC UA clients and servers or to integrate OPC UA-based communication into existing applications.

The KIS department leads the development of open62541. As core maintainers of this open-source initiative, we also review and support many contributions from industry. For commercial users, we provide professional services, including:

- Long term support for past releases
- Access to certification artifacts
- Security patch management (coordinated vulnerability disclosure)
- On-site developer training

Website

For more information, see www.iosb.fraunhofer.de/open62541

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
Wireless communication systems

iosb.fraunhofer.de/DIS

Research areas and expertise

We build the foundations and develop architectures for the (industrial) IoT. 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 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. We automatically evaluate hazards and safety functions for dynamic production. In addition to R&D services, we also offer hands-on training and consulting 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 Industry 4.0 technologies, and Lemgo Digital, a participatory Smart City living lab. In partnership with the Fraunhofer Academy, we also offer courses in IT/OT security for production at the Cybersecurity Training Lab, tailored to the needs of small and medium-sized enterprises.

Highlight topics

Industrial energy checks and retrofit solutions

Due to rising energy costs and increased environmental awareness, the manufacturing sector is placing greater emphasis on energy-efficient production. However, many companies lack transparency regarding their energy usage, making it difficult to initiate corrective measures.

To ensure transparency from the beginning, we have developed several instruments, called INAcarry5G, INAsense and INArice, which are able to quickly collect energy and a variety of other sensor and process data from industrial machines. In combination with thermal imaging, these instruments enable

the identification of weak spots and facilitate quick and efficient improvements. Understanding the correlation between a machine's operating status and energy usage allows for more efficient machine control and better decision-making with regard to when to power it down.

The instruments have been applied successfully in medium-sized companies including IWN GmbH & Co. KG as well as in large companies such as Phoenix Contact GmbH & Co. KG. In 2020, VDMA e. V. — the German mechanical and plant engineering association — selected us to write the "Guideline Retrofit for Industrie 4.0" publication, based on our expertise in the field. The guideline aims to disseminate the knowledge on enabling systematic data acquisition and analysis for aged machinery.

Testing of interoperability and migration of convergent IT/OT real-time communication networks

Communication in industrial automation is changing from the classic hierarchy automation pyramid to the Industrial Internet of Things (IIoT). With the associated interoperability between IT and OT, convergent real-time communication networks can be realized that reach a new level of complexity in terms of the required range of functions and the necessary configuration based on IEEE standards, for example.

Deterministic communication in factory automation with TSN and 5G.

The Fraunhofer IOSB-INA 5G Application Center (www.5g-anwendungszentrum.de, headed by Timo Siekmann) and the TSN Test Lab (www.tsn-testlabor.de, headed by Alexander Biendarra) address these topics and support their partners and customers in topics such as 5G, 6G, wireless local area networks (WLAN), PROFINET, OPC UA FX, time-sensitive networking (TSN) and any other kind of real-time communication solution. In our test labs and the SmartFactoryOWL, we can conduct interoperability tests, performance evaluations of implementations or implementations of new protocol standards. Demonstrators in the SmartFactoryOWL show the potential of industrial Ethernet protocols via 5G routes and the convergent use of several industrial real-time Ethernet protocols with simultaneous network load and transmission of video streams in a single communication network.

Functional safety for dynamic production environments

With its research focus on machine safety for adaptive modular production, Fraunhofer IOSB-INA addresses new challenges in the field of functional safety. Cross-cutting topics include:

- the automation of hazard analysis and advanced risk assessment to define safety functions and ensure safe operation with plug-and-produce. The necessary fundamental procedure was researched in the AutoS² project financed by our regional cluster of excellence "it's OWL".
- The application and use of innovative technologies in functional safety, for example, the functionally safe use of AI in sensor technology for object classification for safe person detection and object classification for AGVs, HRC (CoBots), and perception systems. However, we are also interested in using known technologies in new applications, such as gyro stabilization for innovative autonomous monorail vehicles (MONOCAB).
- Upcoming standards and regulations — we stay up to date on changes and new possibilities in order to help our customers develop their product strategy.

If you want to use machine safety as a competitive advantage in the future, please contact our functional safety engineer Philip Kleen, philip.kleen@iosb-ina.fraunhofer.de.

INArice traverse module equipped with sensors, monitoring an injection molding machine, as an example of contactless data acquisition using optical sensors.

The protective devices of functional safety are automatically analyzed and linked at the adaptive matrix production 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.

EIS

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Research groups

Cognitive autonomous systems
Smart UV-systems

iosb.fraunhofer.de/EIS

Research areas and expertise

The Embedded Intelligent Systems department offers extensive methodological and technological expertise in the field of applied systems engineering.

In the area of mobile machine automation, we have been conducting application-oriented research on autonomous driving and automatic control of mobile systems for many years now. The focus is on modelling, simulation, hardware-in-the-loop testing in the laboratory, as well as validation and testing in real environments. New methods for localization, navigation, path planning, and control are implemented and continuously improved through the use of AI.

In the UV systems technology segment, we are working on the disinfection of flowing media and surfaces, as well as on photocatalytic processes. For example, we are investigating how UVC LEDs can be used to inactivate viruses, bacteria, and molds. We are optimizing the arrangement and control of these UVC LEDs. Using extensive multiphysics simulations, we couple the 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 UV systems. We have the expertise and equipment for the technical implementation of prototypes and small series.

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 equipped with a wide range of equipment for the manufacture, assembly, and testing of electronic systems. Rapid prototyping systems enable us to quickly turn ideas into reality. In the hardware-in-the-loop (HIL) test laboratory, we can evaluate navigation and vehicle control systems using our precise reference measurement technology. Our mobile real-world machine laboratory allows us to perform practical tests with large machines right on site. Our UV test laboratory is well equipped for evaluating and testing UV systems and for validating equipment.

Highlight topics

All-in-one retrofit kit for environmental sensing
For mobile machines to be able to move around autonomously and perform work, they need to sense their surroundings in detail. The Environment Perception (ENVP) Kit we developed lays a foundation for secure navigation

Retrofitting mobile machines with environmental sensing capabilities: the Environment Perception Kit in use.

and manipulation. This compact all-in-one solution incorporates the sensors crucial for this purpose, such as a multilevel 3D laser scanner, 2D Full HD camera, and dual antenna GNSS receiver with inertial measurement unit (IMU), and is easy to add on to existing vehicles.

The ENVP Kit stands out for its rugged construction, flexible energy supply (9–36 V), IP67 protection class, and compact dimensions (830 x 1,100 x 320 mm and just 35 kg in weight). External sensors can easily be integrated via Ethernet and supplied with electricity to adjust the kit to specific research questions. An optional industrial PC, including 5G modem and Wi-Fi, can be added to the kit to maximize connectivity and processing power.

A number of existing algorithms can be used with the ENVP Kit, enabling efficient implementation and adjustment directly on the platform. This means the ENVP Kit offers researchers and developers a fast, convenient entry point for development of autonomous driving and working functions.

Poultry farming: UV disinfection reduces antibiotic use

Improving air quality for enhanced animal welfare, achieving lasting reductions in the use of antibiotics — and thus also the emergence and spread of multidrug-resistant microbes: Those are our goals in the "DesGefUV" project. In partnership with PURION GmbH and Gesellschaft zur Förderung von Medizin-, Bio- und Umwelttechnologien e. V. (GMBU), we are developing a compact device that combines UV disinfection, photocatalysis, and particle filtration. It is able to remove both germs and harmful chemical substances (ammonia, hydrogen sulfide, volatile organic compounds) from the air inside barns.

The device is designed to allow for rapid, flexible integration into existing poultry farming operations. It uses UVC LEDs to continually disinfect the air in the barn. The ultra-short-wave radiation has a powerful microbiocidal effect, and the relatively new LED technology offers advantages over mercury vapor lamps in that it is non-toxic and resistant to vibrations and emits an especially effective wavelength spectrum. It is suited to closed barns and can therefore also be used in piggeries — and unlike antibiotics, it could also prove useful against viral diseases. One of the research questions is how to optimize photocatalysis to reduce harmful compounds, which has thus far mainly been the purview of UVA. The project is receiving funding from the German Federal Ministry of Food and Agriculture (BMEL).

Innovative UV disinfection solutions can reduce the use of antibiotics in poultry farming.

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 applications and data spaces related to Industry 4.0, health, mobility, 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 expertise

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

Applications, products, and services

Our tool suites for industrial production comprise both production control system components and integrated open-source solutions such as the FA³ST toolkit designed to meet the emerging combined requirements from Industry 4.0, International Data Spaces (IDS), and GAIA-X technologies. We design PAISE®, the process model of AI systems engineering, apply it to the systematic design and operation of AI-based complex and critical technical systems, and complement it with software engineering tools for MLOps. Our environmental risk and crisis management systems are built upon WebGenesis® and the FROST® Server, our implementation of the geospatial SensorThings API standard of the Open Geospatial Consortium (OGC). 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/DKE, IEC, IIC, and OGC.

Infrastructure and lab facilities

With the Smart Factory Web, a reference implementation of a blueprint architecture for open 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 along the entire supply chain. We operate the AutomationML test center, a training laboratory for cybersecurity (LLCS), lead the Competence Center Karlsruhe on AI Systems Engineering (CC-KING), and, as project manager, provide key components for the data space of the KI-Allianz Baden-Württemberg e.G.

Highlight topics

AI for water management
AI for water management aims to create a shared data infrastructure using open

AI for water management with SensorThings API.

standards such as the OGC SensorThings API (STA) as a basis for the flexible integration of machine learning algorithms in the water domain. With the FROST® Server, we offer an open-source implementation of the STA for sensor data management and investigate the integration of AI methods via the STA "Tasking Core" extension of the STA using our PERMA® toolkit.

In the NiMo 4.0 project, AI methods are used to predict nitrate levels in groundwater. A data infrastructure based on the FROST® Server was created using data from five German states. The project partners developed several AI algorithms related to nitrate, such as nitrate regionalization, network optimization, and event detection. These algorithms were successfully integrated into the NiMo 4.0 data infrastructure via PERMA®. Measurement data and prediction results are accessible through open standards and can be integrated into various end-user platforms.

The TETRA project develops methods that simplify and accelerate the use of AI in water protection, with a focus on protecting water resources and hydrological ecosystems. The data infrastructure is tested in two different use cases in the German-French region of the Rhine: First, the quality of the river will be measured using new image-based sensors that employ integrated AI procedures. Second, integrated AI models will support the generation of recommendations for the restoration of hydrological ecosystems.

Certificate management for OPC UA networks

The secure operation of modern industrial networks is a major challenge. Communication protocols that allow for protected and authenticated connections are needed to secure these networks. OPC UA, for example, is one such secure, industrial communication protocol. With OPC UA, as with many other protocols, these connections are secured through the use of certificates that enable secure authentication of communication participants. In practice, however, their use requires configuration and management efforts.

To keep this effort as low as possible, the OPC UA standard already includes functions for managing these certificates, even integrated into the protocol. A "global discovery server" (GDS) with certificate management support is required to provide this in practice.

Our open62541-based GDS is an implementation of such a global discovery server with certificate management. It offers the management of registered applications in an OPC UA network, as well as the management and distribution of certificates and trust lists.

The GDS is based on the open-source open62541 implementation of the OPC UA standard and will be published as open-source software.

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

Head of department

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Research groups

Distributed systems
System architectures
Networked information management
Command and control systems

iosb.fraunhofer.de/IAS

Research areas and expertise

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 in attaining 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 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 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 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,
- Lost Earth 2307, an adaptive serious game framework for training image interpreters and other specialists.

Highlight topics

Demand-driven provision of information for Joint ISR/Multi-Domain Operations
Intelligence, Surveillance, and Reconnaissance (ISR) across different armed forces and countries helps to provide key information on time for a joint picture of the situation. This is done using (NATO) standards. This approach makes it possible to ensure that information reaches the right people, as required, and that those people can interpret the information and process it in line with their tasks using software applications.

The IAS department works at several levels in this field. It supports entities that require assistance in aligning operational processes with technical standards and provides feedback on technical feasibility. IAS is also actively involved in various committees in the field of standardization and develops formats, interfaces, and services. One essential part of this is keeping an eye on current trends and developments, including IT security, and evaluating and incorporating them for future solutions. Accordingly, IAS conceptualizes and develops software solutions for data and information distribution, report generation, and ISR management, which are also incorporated into operational overall systems.

For a clearer picture of the work done by IAS, the graphic below shows how Coalition Shared Data can be used to provide information in a distributed reconnaissance network. Data from different sensors (and reconnaissance disciplines) are provided for evaluation and analysis at different locations and by different countries. Plans call for effectively integrating the findings on interoperable data and information provision into other projects and initiatives, such as Multi-Domain Operations.

Unmanned autonomous vehicles
With threats on the rise internationally, protecting critical infrastructures is growing more and more important. Ensuring long-term, across-the-board protection for maritime infrastructure such as liquid natural gas terminals and offshore wind farms is an area of special attention. This is the objective for the HUGIN ("Heterogeneous Unmanned Group of Intelligent Watercraft") demonstrator, which was jointly realized by Fraunhofer IOSB and the Fraunhofer Center for Maritime Logistics (CML) in Hamburg.

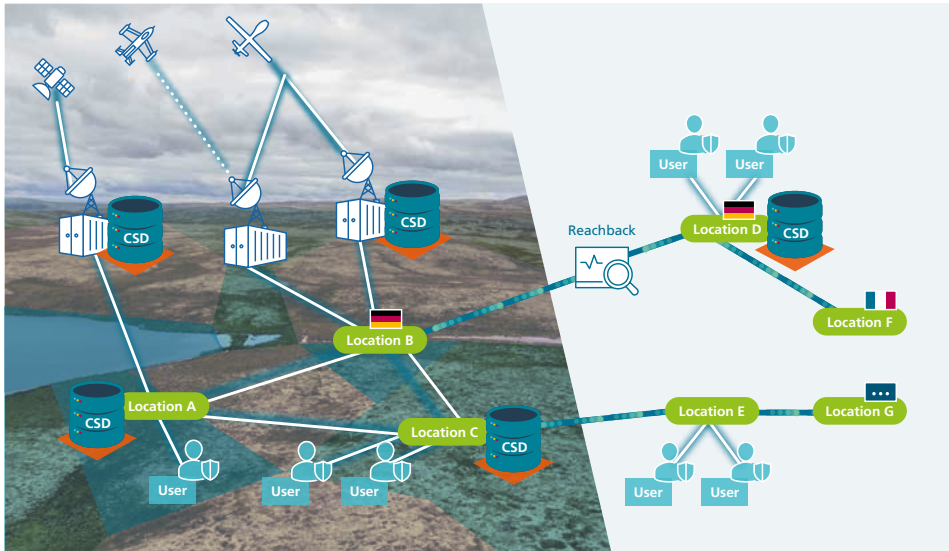
Intelligent, heterogeneous unmanned surface vehicles organized into a team and equipped with different sensors are responsible for surveillance. In addition to the unmanned vehicles themselves, HUGIN consists of intelligence-generating software made up of several layers and components.

- The planning AI is responsible for situational planning and for allocating the available resources to the tasks at hand, autonomously analyzing the situation, and responding to changing requirements, along with flexible planning of missions (patrols, inspections, etc.).
- The responsive AI ensures intelligent control of the heterogeneous collaborative platforms (of the unmanned surface vehicles) on a multi-agent basis.
- The control system includes a number of robust control units that keep the vehicle on its planned trajectory. The control system also allows the operator to monitor the mission from the control station.
- The evaluation layer is responsible for automatically detecting and classifying ships and boats and for correlating the classified ships with the data from the general public automatic identification system (AIS).

HUGIN makes it possible to protect critical maritime infrastructures 24/7, lowers costs in comparison to manned vehicles, and saves time due to the distributed use of multiple platforms and parallel processing of multiple tasks.

HUGIN team in action.

Provision of information in a CSD network.



MIT | Machine Intelligence

The Machine Intelligence department researches and develops automation solutions based on data integration standards as well as artificial intelligence and machine learning methods, 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
Symbolic methods and optimization
Data-based value creation models
Cognitive automation

iosb.fraunhofer.de/MIT

Research areas and expertise

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. To leverage 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 area 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, information, and interaction design.

Applications, products, and services

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 Industry 4.0 to integrate machine and plant data using a plug-and-monitor system. We also aim to automate the interpretation of this data with models that deliver meaningful information. In addition, 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. In close cooperation with both science and industry, we create structured data sets that allow for analyzing the potential of AI, identifying suitable use cases, applying AI algorithms, and networking systems with one another. We thus support companies in using data profitably in the long term and strengthen the innovative, trustworthy, and secure exchange of data in the industry.

Highlight topics

Optimizing production planning by reinforcement learning

The SUPPORT project is a collaboration between the University of Applied Sciences Bielefeld, Miele, and Isringhausen GmbH & Co.

Dr. Jürgen Jasperneite, Director of Fraunhofer IOSB-INA in Lemgo, Dr. Korbinian von Blanckenburg, Dean of the Department of Economics at TH OWL, and Dr. Oliver Niehörster, Head of the Machine Intelligence department at IOSB-INA, are delighted about the collaboration.

The goal of the project is to utilize reinforcement learning for production planning. One of the project's highlights was the successful application of reinforcement learning to a complex real-world use case: a two-stage permutation flow shop scheduling problem (PFSSP) with a finite buffer and sequence-dependent setup efforts in a household appliance production operation at Miele. The objective was to minimize the idle times of the final assembly lines and the setup effort. The results obtained were excellent, with reinforcement learning outperforming all other methods [1, 2]. The next step in the project is to combine reinforcement learning with automated generated simulation models, which will enable the scalability of this approach.

Data-driven business: new customer benefits through data utilization

Data-based value creation models are becoming increasingly important as the amount of data generated in the automated industrial production environment grows. Therefore, Fraunhofer IOSB-INA and the Department of Economics at the OWL University of Applied Sciences (TH OWL) have established a new research area called "data-driven business" at the Innovation Campus in Lemgo. The aim is to develop new business models based on the added value of product and production data, primarily from SMEs. Fraunhofer IOSB-INA and TH OWL are combining an economic perspective with more than ten years of expertise in intelligent automation to enable SMEs to generate more benefits from this data by developing service-centered business models — for example with the aid of artificial intelligence.

Software development for industrial digital twins

Our department has been contributing to the development of industrial digital twins based on international standards such as the asset administration shell (AAS) and OPC Unified Architecture (OPC UA) for more than ten years. We model necessary semantic descriptions of production systems, components, and their communication, e.g., using OPC UA technology, and work on open-source software in a development project together with the Industrial Digital Twin Association (IDTA). Here, the specific focus is on the further development of an open-source server, as well as the official IDTA Engineering tool for the AAS based on C# .NET.

1 A. Müller, F. Grumbach, and F. Kattenstroth, "Reinforcement Learning for Two-Stage Permutation Flow Shop Scheduling — A Real-World Application in Household Appliance Production," in IEEE Access, 2024, doi: 10.1109/ACCESS.2024.3355269

2 Grumbach, F.; Müller, A.; Vollenkemper, L.: Robust Human-centered Assembly Line Scheduling with Reinforcement Learning. In: International Conference on Dynamics in Logistics (LDIC). 2024

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

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Research areas and expertise

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, causality analysis, and environmental sensing. We specialize in developing autonomy algorithms for mobile robots — including construction machines — in unstructured environments and simulation platforms for autonomous vehicles. 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 and products

In the field of process and manufacturing engineering, we develop machine learning tools to monitor, control, and optimize complex industrial production processes as well as water and heat distribution systems for municipalities. In the area of surface inspection, our research is dedicated to exploring image-based methods including deflectometry, optical imaging measurement, and robust sensor evaluation concepts in industrial applications.

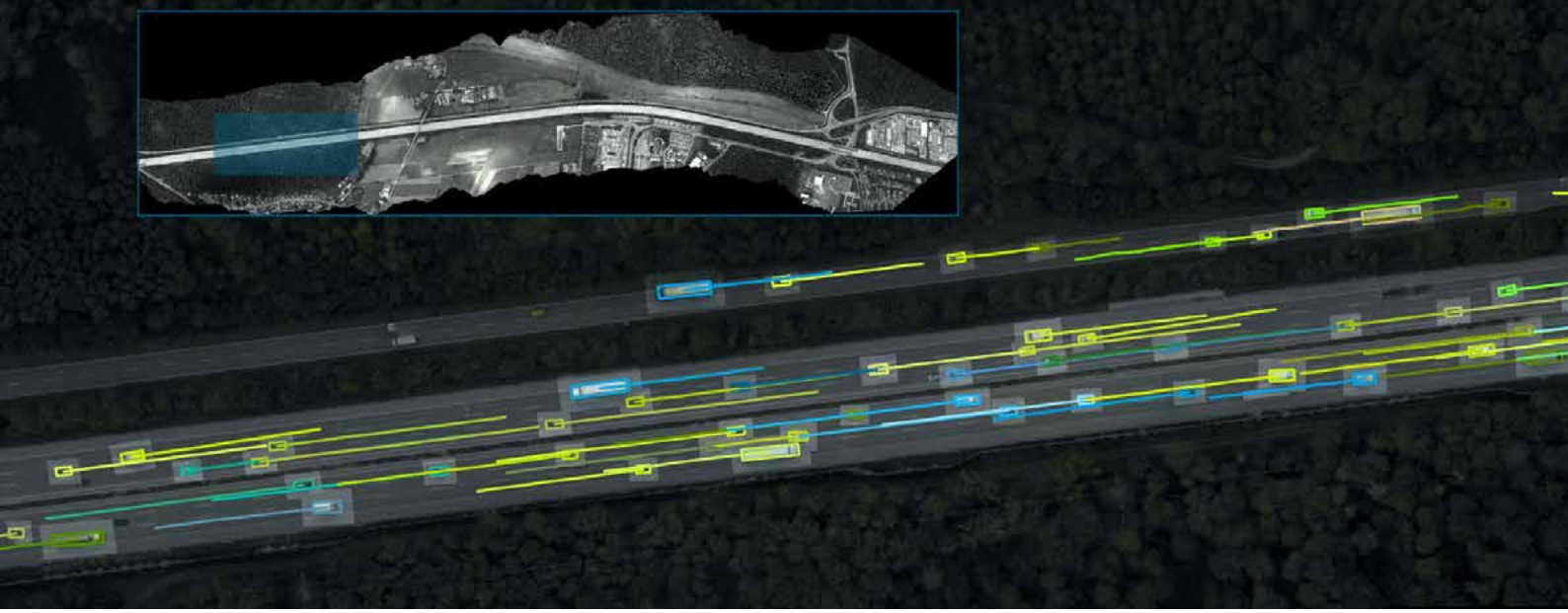
In the dynamic and expanding field of mobility systems, our primary objective is to develop a sophisticated simulation platform for conducting virtual test drives. Additionally, we utilize both ground and aerial video analysis to construct detailed statistical models that accurately depict the behavior of mobility systems. This work is instrumental in designing innovative concepts and algorithms, which are crucial for the advancement and realization of autonomous and cooperative driving technologies.

In robotics, we focus on the development of algorithms for localization and mapping, including environment-interactive path and trajectory planning, safe operation, and controlling of 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, we operate our indoor robots and build autonomous construction machines.

For the development and validation of automated driving functions of mobile systems, two identical test vehicles (VERTEX) are available and approved for automated driving. The



AVEAS — situation analysis based on aerial images.

systems are equipped with numerous sensors and actuators and offer extensive possibilities for data collection and the development of automated driving functions.

Highlight topics

TAPS — underwater and surface mapping of rivers and lakes

Accurately surveying water bodies such as rivers or quarry ponds is a challenging task. Authorities and private port operators need an inventory of current maps, such as of riverbeds or port facilities. This typically requires specialized mapping vessels and trained personnel. This is a costly and time-consuming process, and in many cases mapping is done too infrequently.

Autonomous surface vessels (ASVs) offer a solution to this problem, significantly reducing costs and the need for on-board personnel. As part of a three-year in-house research project, we have developed an autonomous surface vessel that is capable of autonomously surveying a body of water to generate a corresponding 3D map. It uses sonar to scan the riverbed, and optical systems to scan the shoreline and overwater structures. This information is then fused and transferred into a common 3D model of the environment.

The knowledge gained from the project can be applied in a variety of ways. Watercraft can be used for passenger and freight transport on the high seas, on inland waterways, or for logistics chains involving waterways. This also includes the excavation of waterways and the autonomous surveying of shipping channels.

AVEAS — survey, analyze, and simulate traffic situations relevant to safeguarding

The AVEAS project (www.aveas.org) aims to develop scalable methods for data-driven virtual testing of automated and autonomous driving functions. For the quantitative safety validation of automated and AI-based driving functions in simulations, these simulations must model the real world accurately in critical scenarios. This includes simulating the behavior of human traffic participants in risky and near-accident scenarios based on real-world behavioral data.

The goal of AVEAS is to demonstrate how to systematically acquire such real-world data of critical scenarios at diverse accident hotspots across Germany, how to create data-driven behavior models based on the acquired data, and how to enable the quantitative virtual safety testing of automated driving functions.

To this end, AVEAS brings together partners from AI and data analysis (UnderstandAI, KIT, EDI), the automotive industry (Porsche Engineering, Continental, dSPACE), simulation (PTV, Fraunhofer EMI, Fraunhofer IOSB), insurance and safety (Allianz Center for Technology, Fraunhofer IVI), human-machine interaction (GOTECH, Spiegel Institut), and standardization/regulation (ASAM, ADAC, TÜV). Fraunhofer IOSB contributes the traffic data acquisition from aerial images and its OCTANE simulation framework (www.octane.org).

The acquired traffic data is scheduled to be released as FAIR data by the end of the project. It can be used for the development of simulation models, testing automated driving functions, and traffic safety studies.

TAPS — autonomous sensor carrier.

Websites

www.aveas.org
www.octane.org

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 the other main focuses of its research work.

Research areas and expertise

We develop customized and real-world tested 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 those models. We examine 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 and on improving the resilience of water supply systems.

Our main office is located in Ilmenau, but the department also has locations in Rostock and Berlin.

Applications, products, and services

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 performed underwater, even without divers. In the "PREPARE: FORESIGHT" project, we are developing an optoacoustic imaging sensor to support underwater work in poor visibility conditions.

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 TETRA project, which aims to provide tools and methods for AI-based projects in water management. In particular, monitoring the water quality of rivers and the restoration of rivers will be a focus. The topic of flash floods has become relevant again, and a dynamic short-term forecast for flash floods will be created in the PrognoSF project. Furthermore, we work in the field of aquaponic systems, especially with partners based in China. With our location in Berlin, we participate in the Fraunhofer Center for the Security of Socio-Technical Systems (Fraunhofer SIRIOS).

UWR

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Research groups

Underwater vehicles

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Infrastructure and lab facilities

We have a 12 x 8 x 3 meter water tank and a 1,200-bar pressure chamber for testing our maritime systems and components. Our diving drones as well as our infrastructure are available for client-specific projects such as integrating new sensors, collecting data in real environments, or validating sensors and components in the test tanks of the department.

The department runs two fully operational ROVs. The ROVs are very agile, remotely operated underwater vehicles with diving depths of up to 150 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.

The DEDAVE 2000 is an autonomous underwater vehicle (AUV) with a diving depth of up to 2,000 meters and a large payload range with versatile sensor equipment.

Highlight topic

Automated monitoring of fish stocks
Fish stock monitoring for commercially important fish populations typically relies on data from industrial fishing and highly invasive net sampling with research ships, entailing enormous expense for personnel and time-consuming ship operations. Moreover, this approach results in discontinuous data acquisition, both temporally and spatially.

The UFOTriNet project aimed to create an automated, cost-effective, non-invasive, and flexible system as an alternative to ship-based monitoring of fish stocks, and then to test it under real conditions. Such a system would contribute to a sustainable and evidence-based fisheries policy. During the project, both a mobile and a portable UFO (underwater fish observatory) were developed, built, and combined with an already existing stationary observatory. The newly connected trilateral monitoring network was tested at two locations in the southwestern Baltic Sea.

All three systems are modular and expandable with additional sensors, with the core unit consisting of a stereo camera system and an imaging sonar. This approach combines optical data from the near field with acoustic data from the far field into a coupled hybrid system. On this basis, all three UFO variants should be used with standardized automatic pattern recognition algorithms and later be optimized so that the system can determine species, size, and weight with at least 95 percent certainty.

The UWR department was responsible for designing, building, and evaluating the mobile UFO. One main feature of the new underwater vehicle is its ability to be used both as a remotely operated and an autonomous vehicle due to the integration of a new, compact, and highly precise navigation sensor in the vehicle. Additionally, we developed new control algorithms to optimally use the high-end sensor and enable new vehicle modes for fish monitoring, such as slowly following a species after detection in the hybrid algorithm. The developed software also includes an intuitive planning tool for autonomous missions with different mission modes and the definition of an exploration area that must not be left, in order to prevent system loss.

The basic functions were tested on board several research and fishery vessels on the Baltic Sea in 2022 and 2023. The mobile UFO collected a high volume of sensor data to be processed by the AI algorithms for species detection, classification, and size determination. The system has already garnered interest from industry customers with regard to biodiversity monitoring of their offshore facilities.

The mobile UFO, aka ROV BETTA, is being tested onboard the "Littorina" research vessel shortly before deployment in May 2023.

HAI | Human-AI Interaction

The Human-AI Interaction department develops smart and innovative AI-based assistance systems for human-machine interaction. Privacy by design ensures the responsible handling of personal data.

HAI

Head of department

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Research groups

Decision support systems
Perceptual user interfaces
Interactive systems
Explainable AI

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Research areas and expertise

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 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, in virtual and augmented reality as well.

Applications and products

Our systems and expertise are used in a wide variety of contexts. Our assistance systems support image analysts in reconnaissance tasks (such as identification of vehicle type) and security guards in surveillance tasks (e.g., monitoring maritime areas). Our camera-based perception components enable autonomous vehicles to understand the occupants' and driver's activities, for example 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 system visualizes all types of geodata and integrates AI-based algorithms which detect situations of interest. It supports users in various application areas such as military situational awareness, monitoring critical infrastructures, and surveillance of maritime areas. It allows experts to collaborate on crisis scenarios without being present in the same physical location, and the virtual reality version supports the intuitive analysis of 3D geodata.

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 for Traffic Sciences (WIVW). In addition, we run a seating buck unit to demonstrate our monitoring and assistance systems in a mobile setup that consists of a driver seat, steering wheel, and multiple displays.

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. It can be

operated on various devices — from tablets and desktop PCs to VR glasses.

Highlight topics

Advanced Occupant Monitoring System
Occupant monitoring systems are becoming increasingly important for vehicle safety and comfort. Our state-of-the-art system surpasses conventional methods by using optical sensors that detect all occupants within the vehicle. It not only identifies the driver but also recognizes the 3D body poses and movement behaviors of all individuals present. This advanced technology allows for precise differentiation between various activities and levels of distraction. Consequently, it enhances both safety systems and in-car comfort.

Real-time 3D body pose detection, achieved without collecting biometric data and thus without compromising privacy, is the core of this system. It uses individual 3D cameras or multiple 2D cameras, enabling accurate tracking of body joints. This includes eye, elbow, and wrist positions, making it possible to interpret pointing gestures with centimeter precision. The system can recognize gestures from any direction, not just traditional seating positions or prescribed interaction areas.

As vehicles become more automated, drivers and passengers gain more freedom for secondary activities. Our system is instrumental in recognizing these activities in 3D space, facilitating safe and efficient in-car interactions. It can differentiate up to 35 activities, such as eating, sleeping, reading, or making phone calls, thanks to machine learning processes.

Fraunhofer IOSB's Advanced Occupant Monitoring System provides key insights into the driver's state and in-vehicle context, enabling a tailored approach to assistance functions. By recognizing activities, the system can predict the driver's intentions and improve the overall driving experience, while ensuring that safety remains a top priority.

Virtual Control Room for the Arctic
Climate change makes the Arctic seas more navigable, significantly shortening the shipping route between Europe and Canada and other countries. However, operators responsible for monitoring the Arctic maritime areas will have to monitor considerably more activities. To address this issue, 13 partners from research, industry and potential future users have joined forces in the EU project AI-ARC, with the aim of improving the conditions for maritime surveillance in a way which ensures that the cognitive load for operators does not increase and their situational awareness even improves despite higher traffic volumes.

Our central contribution is a virtual control room (VCR) based on the technologies of the Digital Map Table (DigLT). This collaborative platform for visualizing and analyzing situations seamlessly integrates the results of various artificial intelligence (AI) algorithms for detecting anomalies in shipping traffic. It also serves as a central hub for effective communication and coordination between Arctic stakeholders. This not only simplifies decision-making when monitoring maritime shipping traffic, but also helps to overcome the challenges posed by climate change and increasing human activity in the region. In addition, the DigLT can be used via web interfaces or virtual reality (VR).

In addition, Fraunhofer IOSB contributes AI-based anomaly detection algorithms that autonomously detect ships involved in critical situations such as illegal fishing, staying close to critical infrastructure, and deviating from shipping routes. An algorithm that warns of ice floes has also been developed. These algorithms combine knowledge and data-driven AI approaches and offer an editor so that users can describe new situations of interest without the need for any IT support.

Seating buck with integrated Advanced Occupant Monitoring System.

OBJ | Object Recognition

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

OBJ

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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 expertise

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 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 carry out operations more efficiently. 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 the study team test and analyze a wide range of sensors and various operating scenarios. Mobile Distributed Situation Awareness (MODISSA) is the department's experimental platform for hardware evaluation and software development on wheels. It is a valuable asset used to acquire sensor data for further research and development and to evaluate experimental technical approaches in military contexts.

Highlight topic

Neural radiance fields (NeRF) from satellite images

Satellite images play a crucial role in various fields, including defense applications, disaster management, and environmental monitoring. Acquiring 3D information is essential for many use cases, such as simulation and data augmentation. Due to the rapid development in recent years, current frameworks are capable of reconstructing 3D structures from plain satellite images, even for challenging real-world scenarios.

As image-based reconstruction is a complex process, modern pipelines subdivide the task into individual sub-problems such as matching feature correspondences, estimating camera poses, and computing scene structures. In particular, the latter is highly challenging because it is still not clear how to determine an optimal

Comparison of a synthesized image (right) with the corresponding ground truth (left).

representation. For instance, point clouds inherently lack information in unoccupied areas, while other explicit representations such as (textured) meshes are difficult to compute for fine grained structures.

Neural radiance fields (NeRF), which use an implicit representation of the scene, have emerged as a promising alternative. They offer a novel way to model complex scenes based on deep learning. NeRF-based models capture not only the intricate details of the scene's geometry, but also cover specific appearance features such as the scene's material properties and the scene's radiance, accounting for specific lighting conditions. NeRF-based models thus especially excel when synthesizing realistic images for novel viewpoints.

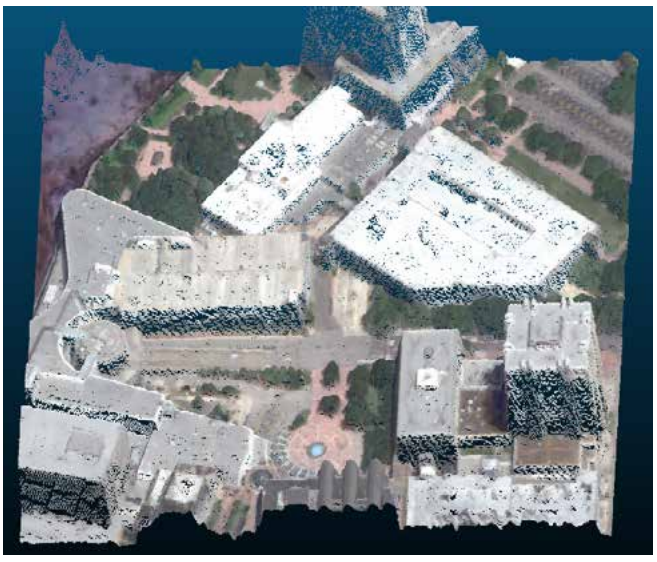
In recent years, we developed a framework based on modern structure-from-motion (SfM) and multi-view stereo (MVS) methods. The framework is capable of reconstructing multi-date satellite images and yields highly competitive results in the form of textured meshes. Now we have enhanced the framework with a component that generates NeRF-based models, in order to leverage the potential of current NeRF models in the domain of satellite imagery.

Since the satellite domain poses specific challenges to the reconstruction task (such as large distances between cameras and scene, complex camera models, and specific radiance conditions), this is not a straightforward process. Our framework supports the adjustment of several key aspects, including the adaptation of camera models, ray generation, coordinate reference systems, and model structures. This allows us to substantially simplify the integration process.

Since many use cases rely on metric measurements between different scene structures, we also investigated the derivation of explicit model representations. A comparison of the reconstructed 3D structures with results obtained by state-of-the-art SFM and MVS pipelines demonstrated comparable quantitative results.

Currently, the computation of NeRF models is relatively heavy compared to modern SFM and MVS implementations — both in terms of memory and computation requirements. However, based on the fast evolvement in this domain, NeRF-based models hold the potential to substantially alter the 3D reconstruction of satellite imagery.

3D point clouds based on two implicit scene representations reconstructed with a NeRF model.



SZA | Scene Analysis

The research conducted by the Scene Analysis department meets the need for rapid, geo-referenced interpretation in the fields of intelligence, surveillance, and reconnaissance.

SZA

Head of department

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Research groups

Image interpretation
Geo intelligence
SAR image analysis

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Research areas and expertise

We develop methods that efficiently process and utilize 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 utilizing 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, products, and services

Our airborne multi-sensor platform is designed to monitor terrestrial 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 necessitates 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.

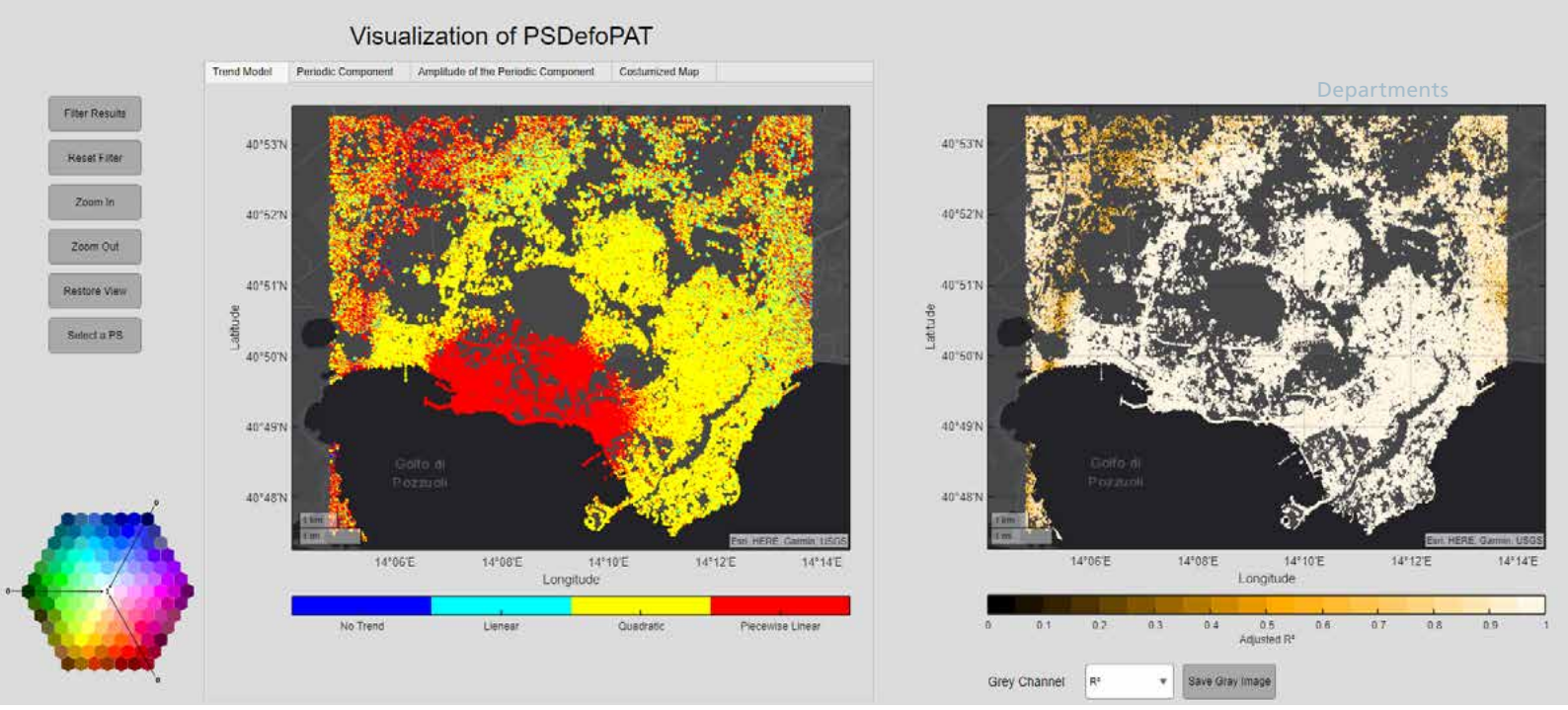
With our expertise in remote sensing, we solve tasks in application fields including distant inspection and smart farming.

Highlight topics

New approach to ground surface deformation measurement from satellite data
Advanced differential synthetic aperture radar interferometry algorithms are techniques used to document ground surface deformation. Typically, the results are displayed as a map of the mean deformation velocity of each measuring point in the data set.

However, only analyzing the mean deformation velocity neglects the different kinematics the deformation process may have. For example, a landslide changes its velocity depending on the water content of the sliding material, or a bridge deforms with a periodic pattern in correlation with the ambient temperature. Both phenomena are misrepresented in a display of mean velocities.

Our tool, PSDefoPAT, [1] was designed to assign each measuring point a best-fitting



Visualization of PSDefoPAT results generated from displacement time series by the European Ground Motion Service.

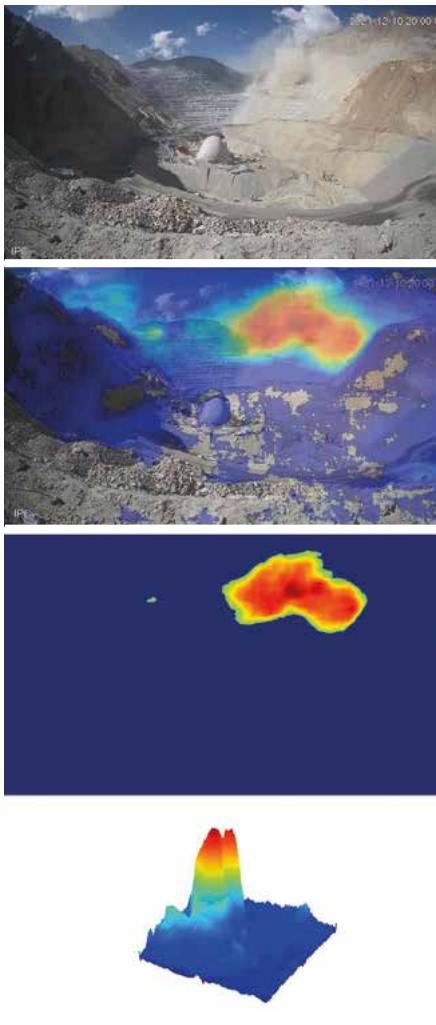
time series model based on its displacement time series. The tool separately determines the periodic and long-term trend components of the displacement time series using different regression models and significance tests. The image above shows a visualization tool that displays selected features of the best-fitting time series models and their goodness-of-fit as colored maps. The visualization facilitates an intuitive interpretation of the spatial distribution of the selected features and, consequently, the kinematics of different deformation processes.

AI-based dust cloud detection helps reduce cryosphere pollution

Surface mining, such as open-cast mines, releases dust emissions that not only negatively impact nearby workers and their surrounding environment. Especially in the case of high-altitude copper mines in Chile, the dust can settle down on nearby glaciers, which causes them to retreat faster due to the lowered ice-albedo of the dust cover, therefore accelerating global warming. The operators of these mines use various methods to control dust emissions and reduce them to an acceptable level, such as water spraying before and after blasting, covering open areas, and reducing air currents by adapting the order of ore mining. However, to optimally apply such measures, close monitoring and a better understanding of dust emissions is necessary.

In a project, we provided a proof-of-concept for detecting airborne dust in open air mines using standard camera surveillance technology combined with advanced deep neural net machine learning techniques. For this purpose, a ground truth annotation workflow based on the given requirements of the data and the specifications of the final dust detection algorithm was researched, developed, and realized. Using the knowledge gained during the annotation phase, Fraunhofer IOSB designed, trained, and evaluated a dust detector based on a density estimation neural network architecture. The dust detection algorithm showed promising results on the test dataset.

As part of the proof-of-concept, the core components "dust detection" and "dust opacity estimation" were included in our "DustCamVision" framework and successfully deployed at the client's facilities. The system is able to detect and track dust clouds, thus providing the insights needed to avoid dust emissions to the best possible extent.



Open-pit copper mine in the Chilean highlands with dust cloud detection result. The opacity estimate is color-coded or displayed in 3D as elevation.

1 Evers, M., Thiele, A., Hammer, H., Hinz, S. (2023): PSDefoPAT—Persistent Scatterer Deformation Pattern Analysis Tool. Journal of Remote Sensing, Vol. 15, No. 19, 4646, https://doi.org/10.3390/rs15194646, p. 26

VID | Video Exploitation Systems

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

VID

Head of department

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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 expertise

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, maritime SaR (search and rescue), and other environments 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, products and services

Some of the systems we have developed fulfill the highest industry and NATO standards for operational software products. Our ABUL (Automated Image Exploitation for UAVs) system, for example, is in service with the German armed forces and has been used in the missions in Mali and Afghanistan. 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) system. In Mannheim and in Hamburg, 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. Furthermore, we transferred and optimized various algorithms to the maritime domain, e.g., for search and rescue applications.

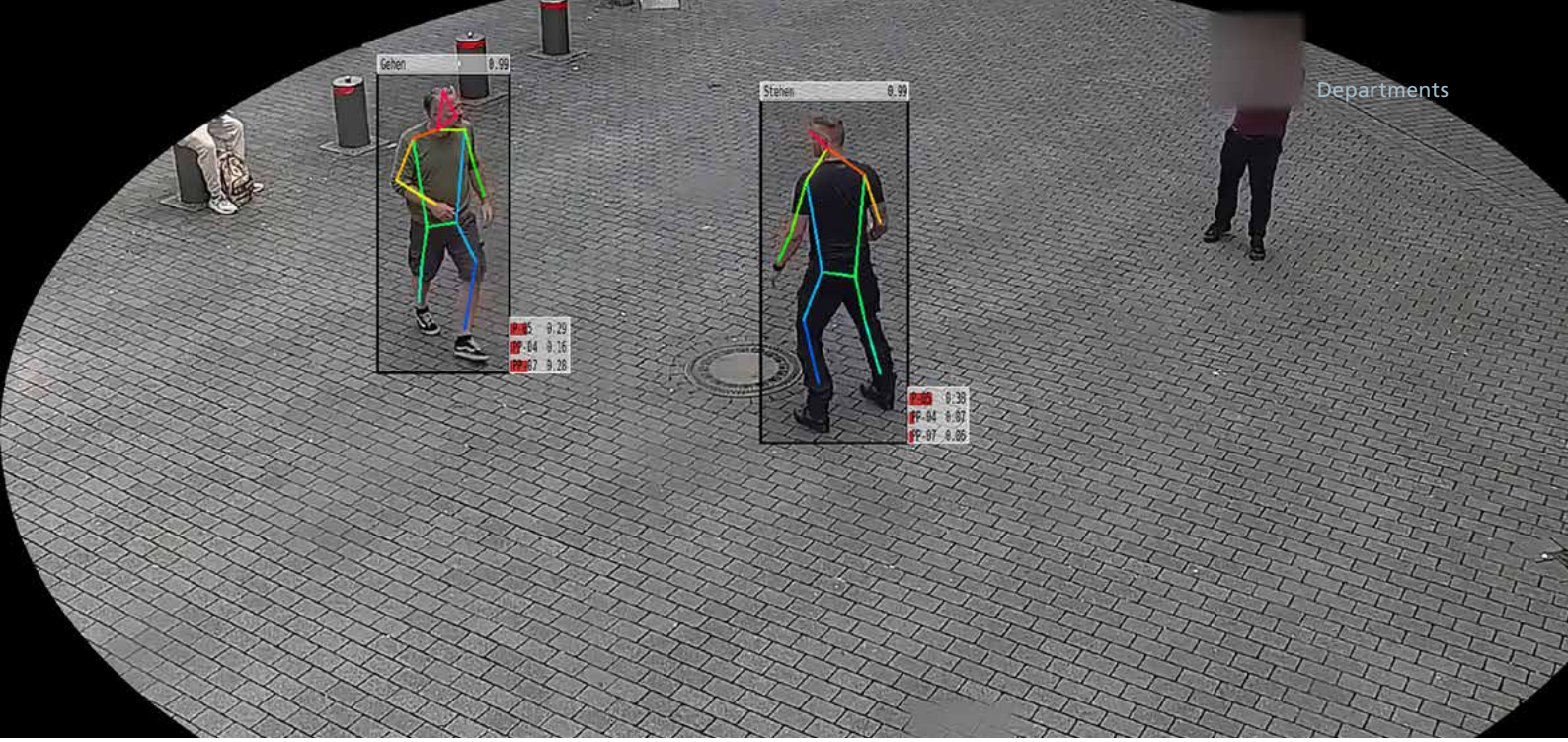
Infrastructure and lab facilities

ABUL development, setup and test lab.

Highlight topics

Intelligent video analysis in public spaces II
VID has been working for many years on intelligent image and video analysis for prevention and forensic purposes. We use the latest AI methods for video analysis, test them in real applications and continuously develop them further. This includes projects in Hamburg and Mannheim, in both cases in close cooperation with the local police department. Other cities are under consideration.

Our goal is to develop an assistance system that alerts video observers in the police command and situation center to relevant situations. This way, the officers do not need to constantly monitor the images from numerous cameras, but only need to verify the hints



Digital skeletons of a scene staged by the Hamburg police, generated with our AI-based pose estimator.

generated by the AI system. This makes it possible to intervene at an earlier stage. At the same time, maximum data protection is ensured. This is primarily due to the fact that the AI system first reduces people to stick figures. A stick figure has no identity, no gender, no skin color, no origin, etc. Nevertheless, by analyzing its movement patterns, attacks can be detected.

During last year's six week test run at Hamburg's Hansa-Platz the system detected eleven police-relevant incidents, including one case of dangerous bodily injury: a person already lying on the ground was kicked in the head. Only our system reported this critical incident to the command center, while none of the passers-by called the police. A police spokesman summarized: "The added value, i.e. the early detection of dangerous situations including rapid police intervention, can be considered as given."

Since in Hamburg, unlike Mannheim, an existing camera network (cameras, installation locations, detection areas) was used, the test run shows that our system can also be successfully used with an existing camera infrastructure. A two-year follow-up project is planned in Hamburg, starting in 2024.

The project in Mannheim has been extended.

Protection of critical infrastructures

The main topic of the VID department is the protection of people with the help of video analysis methods. Whether in public spaces with regard to protection against physical attacks, against mass panic at major events, whether protection against drowning in maritime applications or in the case of flood disasters, or, in this case, the protection of critical infrastructures against assaults.

Military field camps are an example of such critical infrastructures. Methods developed for their protection will be applicable to airports, port facilities, railway stations, government buildings, major events, or religious institutions. In each case, the aim is to detect the relevance of static objects (e.g., abandoned suitcases), objects moving in unwanted places (e.g., vehicles), and the behavior, or equipment (e.g., weapons) of people.

In 2024, together with two other Fraunhofer IOSB departments, we will realize an all-weather, day-and-night capable system to record and evaluate the surroundings of critical infrastructures over a wide area. This system will be equipped with high-end sensors, control panels, processing hardware, and sophisticated AI algorithms. The fundamental software, however, can be transferred to "smaller" situations. For example, for monitoring the entrances to vulnerable facilities.

Contact

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Protection of critical infrastructures
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VBV | Variable Image Acquisition and Processing

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

Head of department

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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 expertise

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 from 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 quickly and accurately.

We utilize computational imaging methods that 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 cannot be interpreted by the naked human eye yet, but when adequately processed by the optimized algorithms, can yield results that are superior to those of a comparable conventional system.

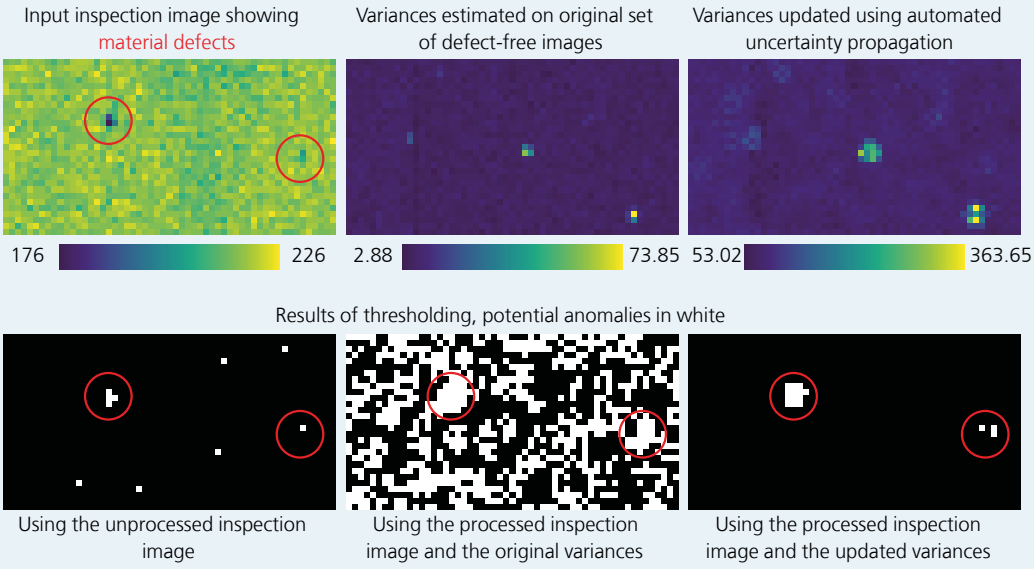
Applications and products

Our research activities cover various artificial vision applications. Tackling challenging open questions in the field of automated visual inspection is 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, thus producing 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, such as for detecting contaminants in food products using anomaly detection or for synthetically increasing the resolution of images acquired with a low-quality microscope lens.

Highlight topics

AutoUncertainty
When using artificial vision systems to automate a certain task (e.g., inspecting produced goods, classifying biological samples, or reacting to obstacles in autonomous driving), images are usually acquired with a camera and processed by algorithms, before eventually a decision is obtained. However, interfering factors like dust, vibrations etc. represent sources of measurement uncertainty that can have a major impact on the quality of the acquired images. It can be crucial to know the extent to which those uncertainties had an effect on the decision made. The traditional method — to analytically propagate the input uncertainties through the measurement



Experimental results of the implemented anomaly detection framework: Without using AutoUncertainty to calculate the correct pixel-wise statistics, several false events would have been detected (lower left image). The correct statistics allowed to only detect the actual material defects (lower right image).

process — turns out to be intractable for complex algorithms as they are used in image processing, which might even involve deep neural networks with millions of parameters.

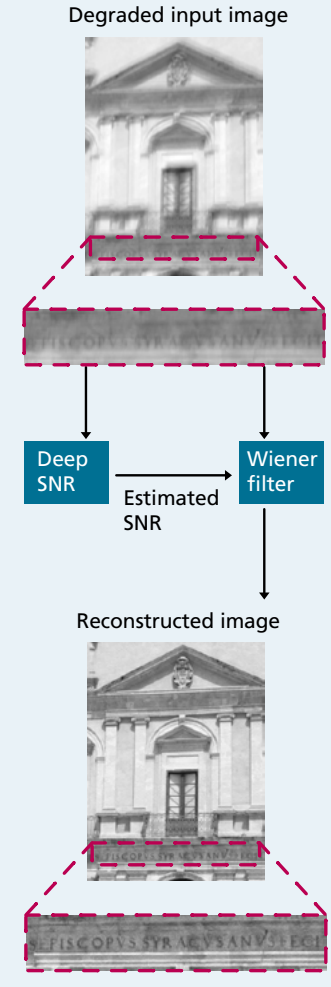
Fortunately, in many cases our AutoUncertainty [1] framework can completely automate the process of uncertainty propagation. It combines the classical method of Gaussian uncertainty propagation with the modern concept of automatic differentiation. Gaussian uncertainty propagation provides a formal way to propagate uncertainties through arbitrary functions, but requires to calculate the gradient with respect to all input parameters. In image processing, where the input data (images) has millions of parameters (pixels), this cannot be done manually, but by formulating the targeted algorithm in a programming language or framework that supports automatic differentiation (e.g., PyTorch or JAX).

We have used AutoUncertainty to realize a visual inspection system based on anomaly detection. For a sample of defect-free instances of the produced object, we calculated pixel-wise statistics, treated the standard deviations as input uncertainties, and used AutoUncertainty to propagate them through our image processing pipeline. By comparing the processed inspection images of yet unseen objects with the propagated output uncertainties, we realized an interpretable way of checking the deviation from the intended appearance.

DeepSNR

When capturing scenes with a camera, the resulting images are often degraded due to various reasons, such as motion blur, imperfections of the employed camera system (e.g., available space limiting the number of lenses), or because the object was out of focus. One of the image processing methods that try to mitigate these effects is the well-known Wiener filter, which tries to invert the image degradation in the Fourier space (i.e., the spatial frequency domain). To avoid the amplification of unwanted noise components, the intensity of the filtering for each spatial frequency is adapted depending on the signal-to-noise ratio (SNR). Although the Wiener filter is theoretically optimal, until now, the required knowledge of the SNR has greatly hindered its practical applicability.

To mitigate this drawback, we researched a machine-learning approach, called DeepSNR, which is capable of estimating the SNR of a degraded input image on a per-spatial frequency basis. We train DeepSNR with pairs of ground-truth SNRs and magnitude spectra of degraded input images. Tests on the widely used non-blind image deconvolution dataset of Sun et al. [2] show the achievable reconstruction performance of the Wiener filter when used in concert with DeepSNR.



Example application of Deep SNR-based Wiener filtering of a degraded input image from [2].

1 J. Meyer, M. Hartrumpf, T. Längle, and J. Beyerer, "Visual inspection via anomaly detection by automated uncertainty propagation", in Unconventional Optical Imaging III, M. P. Georges, G. Popescu, and N. Verrier, eds., Strasbourg, France: SPIE, May 2022, p. 81. doi: 10.1117/12.2621146

2 Libin Sun, Sunghyun Cho, Jue Wang, and J. Hays, "Edge-based blur kernel estimation using patch priors", in IEEE International Conference on Computational Photography (ICCP), Cambridge, MA: IEEE, Apr. 2013, pp. 1–8. doi: 10.1109/ICCPhot.2013.6528301

Facts and figures

2022–23 in numbers

>230

committee memberships

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

54

trade fairs and exhibitions

We presented our technology at trade fairs such as Hannover Messe, E-world energy & water, and IAA Mobility as well as specialist conferences and theme days. We also attended six career shows.

101

teaching activities

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

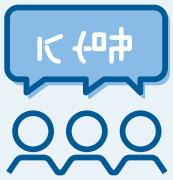
≈150K

website visits

In 2023, our institute's web pages received approximately 150,000 external visits, originating from about 120,000 unique visitors. That's about 15 percent more than in 2022.

4

visiting scientists



worked with us for longer periods of time, starting from three months.

>600

journal and conference papers

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

22

doctorates

Twenty-two researchers working at Fraunhofer IOSB passed their doctoral examinations in 2022 and 2023.

>1,500

participants

attended special events and conferences organized or co-organized by Fraunhofer IOSB and its scientific staff.

21

patents granted

Applications for a further 44 patents have been disclosed in 2022 and 2023. In addition, five 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 progress report:

www.iosb.fraunhofer.de/progress-report-2024

Advisory board

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HENSOLDT Sensors GmbH, Taufkirchen

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Prof. Dr. Cornelia Denz
Westfälische Wilhelms-Universität Münster, Münster

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MBDA Deutschland GmbH, Schrobenhausen

Dr. Christian Martens
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Dr.-Ing. Jörn Oprzynski
Siemens AG, Karlsruhe

Ministerialrat Jürgen Oswald
Ministerium für Wirtschaft, Arbeit und Tourismus Baden-Württemberg, Stuttgart

Jana Podßuweit
Thüringer Ministerium für Wirtschaft, Wissenschaft und Digitale Gesellschaft (TMWWDG), Erfurt

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Phoenix Contact GmbH & Co. KG, Blomberg

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Bundesministerium der Verteidigung, Berlin

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Universität Bremen, Bremen

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Dr. Thomas Steckenreiter (Chair)
Samson AG, Frankfurt am Main

Dr. Isabel Thielen
Thielen Business Coaching GmbH, München

Ministerialrat Dr. Dirk Tielbürger
Bundesministerium der Verteidigung, Bonn

Internal working groups

Automotive und assistance systems
Chair: M. Sc. Jens Ziehn | MRD
Participating departments:
IAD, MRD, VID
Consultants: Univ.-Prof. Dr.-Ing. habil. Pu Li,
Prof. Dr.-Ing. Rainer Stiefelhagen

Autonomous systems
Chairs: Dr.-Ing. Janko Petereit | MRD,
Prof. Dr.-Ing. Andreas Wenzel | EIS
Participating departments:
DIS, EIS, IAS, KES, MRD, VID
Consultant: Prof. Dr. Georg Bretthauer

End-to-end software development
Chair: M. Sc. Philipp Hertweck | ILT
Participating departments:
depending on topic

Event based vision
Chair: Paul Bäcker | SPR
Participating departments: OPT, SPR
Consultants: Prof. Dr.-Ing. Uwe Hanebeck,
Prof. Dr.-Ing. habil. Björn Hein,
Prof. Dr.-Ing. Michael Heizmann,
Prof. Dr. rer. nat. Bernd Jähne,
Prof. Dr. rer. nat. Wolfgang Karl,
Prof. Dr.-Ing. Rainer Stiefelhagen

Large language models
Chair: Dr. rer. nat. Almuth Müller | IAS
Participating departments:
DIS, EIS, IAS, ILT, KES, KIS, LAS, MIT, MRD, OPT,
SIG, SPR, SZA, UWR, VID

Machine learning
Chairs: Dr. rer. nat. Constanze Hasterok | KIS,
Dr.-Ing. Christian Kühnert | MRD
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