Fraunhofer IOSB

Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB

Progress report 2025/2026

Technology that Matters: Turning Ideas into Impact

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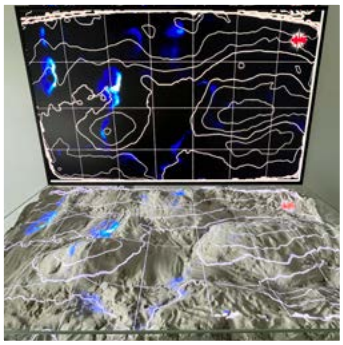

The cover image shows a macro view of the MilitAR Sandbox, a flexible experimental environment used to explore how digital technologies interact with complex real world systems. Reduced to structure, materiality and light, the photograph invites reflection on how impact is created: in experimental spaces where ideas take shape, assumptions are challenged and research begins its journey into practice. Transfer, ultimately leading to deployment, starts long before that—in environments that allow exploration, iteration and learning.

Turning Ideas into Impact

Ideas and innovations are widely regarded as Germany's most important resource. Unlike other economies, our country cannot rely on abundant raw materials or a large supply of low-cost labor. Its prosperity, resilience and future viability depend to a significant extent on the ability to transform knowledge into tangible economic and societal benefit. Yet, while ideas are plentiful, their translation into impact is anything but automatic.

In recent years, the gap between technological potential and real-world effect has become increasingly visible. Economic growth is faltering, transformation processes are gaining urgency, and the contribution of science and technology to addressing these challenges is coming into sharper focus. In this context, excellence in research alone is no longer sufficient. What matters is whether new approaches, methods and technologies find their way into practice—robustly, responsibly and at scale. Transfer, in this sense, is not an optional add-on, but a prerequisite for relevance.

This understanding lies at the core of the Fraunhofer model. Positioned between fundamental research and application, Fraunhofer is tasked with systematically translating scientific insight into impact—in close interaction with industry, public authorities and society. The intended balance between industry revenue and competitively awarded public funding is not merely a financing mechanism; it is a structural commitment to measurable benefit. Fraunhofer's 2025 motto "Transfer for our future" reflects this mandate and underscores its continued importance.

Impact, however, extends beyond immediate economic returns. It also encompasses contributions to security, sustainability, resilience, and the ability of institutions and infrastructures to act under changing conditions. At Fraunhofer IOSB, this broader understanding of impact shapes our work. Our research addresses complex socio-technical systems in which technologies interact with physical environments, organizational structures and human decision-making. Creating impact in such contexts requires more than technological innovation; it requires integration, validation and a deep understanding of application domains.

Turning ideas into impact is therefore a process—one that begins long before deployment and continues well beyond it. This Progress Report highlights how we contribute to this process: by developing technologies, methods and systems that enable ideas to mature, to be tested in realistic settings and ultimately to unfold their effect in practice.

Preface

Dear Reader,

Fraunhofer has faced considerable economic pressure over the past two years. Fraunhofer IOSB, however, has remained on solid ground. We have continued to grow, supported by a strong order situation, a broadly diversified portfolio and substantial investments in future-oriented capabilities. This breadth makes us resilient and enables us to address changing needs across industry, public authorities and security-related domains.

A particularly encouraging signal is our Rho-Wi, the ratio of business earnings to operating budget, which reached a record value of 37 percent in 2025. For us, this figure is more than a business indicator. It shows that our expertise is in demand and that the Fraunhofer model is working: public funding, pre-competitive research and direct cooperation with customers reinforce one another. A strong Rho-Wi value reflects successful transfer into concrete applications and creates room for developing ideas further, building demonstrators, strengthening infrastructures and preparing new fields of application.

This Progress Report shows how varied these transfer paths are. Results find their way into practice through industrial collaborations, licensing, standards, public-sector pilots, spin-offs, continuing education, open infrastructures and strategic networking formats. The examples presented in the following pages make clear that transfer is not a single route. It is a portfolio of pathways that must be pursued deliberately, with the right partners and with a clear view to application.

At the same time, we are investing in capabilities that will shape future demand. The Humanoid Robots Experience Lab and our high-energy laser infrastructure are examples of how we build up expertise and experimental environments early in fields that are highly dynamic, technically demanding and relevant to future applications. Such investments strengthen our ability to assess emerging technologies realistically, develop them responsibly and translate them into robust solutions where they can create tangible benefit.

This forward-looking perspective is also reflected in our growing engagement in security and defense, where technological sovereignty, resilience and operational capability have gained new urgency. In Baden-Württemberg, the planned Innovation Campus Security and Defense, emerging from a Round Table on the same topic, is intended to provide a framework for closer networking between research, industry, public authorities and users. As part of this campus, KIT, Fraunhofer ICT and Fraunhofer IOSB are pursuing plans for an innovation center for drones and counter-drone technologies in Karlsruhe. Such structures help align scientific expertise, technological development and application needs at an early stage—an important prerequisite for effective innovation.

We are also developing the structures that enable transfer. The recent sharpening of our business units and the newly defined role of Business Developers strengthen the link between scientific expertise, market outreach and concrete application demand. They help us identify needs more systematically, connect competences across departments and sites and translate transfer opportunities into projects.

Prof. Dr. rer. nat. habil. Marc Eichhorn (left) and Prof. Dr.-Ing. habil. Jürgen Beyerer, Heads of Institute, Fraunhofer IOSB

This structural development is also reflected at the level of institute management. Prof. Marc Eichhorn, who has built up the field of laser technology at Fraunhofer IOSB and holds the Chair of Optronics at KIT, has joined the institute leadership as Head of Institute alongside Prof. Jürgen Beyerer. This step reflects our broadened technological spectrum, from light generation, propagation and detection to image exploitation, AI-based interpretation, robotics and system integration. Bringing these competences together even more effectively will strengthen our ability to develop solutions for key challenges in industry, public services and security.

The examples in this report also show what is needed for ideas to take effect in practice: close interaction with customers, users, research partners, public institutions, standardization bodies, start-ups and established companies. Transfer requires experimentation, validation, trust and persistence, as well as people who are willing to move ideas beyond the laboratory and into the complexity of real applications. We would therefore like to thank our employees, partners and customers for their commitment, confidence and cooperation over the past two years. And we invite you, as readers of this Progress Report, to explore with us where our expertise can contribute to your challenges. Let us continue to turn ideas into impact—together.

Sincerely,

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

Prof. Dr. rer. nat. habil. Marc Eichhorn
Head of Institute, Fraunhofer IOSB

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Highlights

1. Generating impact: selected transfer and innovation success stories

Fraunhofer IOSB delivers impact through deliberately pursued transfer pathways—industrial collaborations, market-ready software and systems, standards and demonstrators, public-sector pilots, spin-offs and continuing-education offerings. The examples below illustrate how these pathways translate research into added value beyond individual projects.

Video produced for a Hannover Messe 2026 campaign showcasing the successful EVORIS collaboration:

Industrial collaboration: revolutionizing wood-based panel production

Industrial AI creates impact only when it performs reliably in real production under changing conditions and delivers measurable added value in day-to-day operations. This is what our collaboration with Dieffenbacher—a manufacturer in the field of wood-based panel production—demonstrates: our scientifically developed AI methods were translated into concrete functions for the EVORIS platform, making production processes more transparent, robust and efficient through data-driven insights.

The challenge lies in the highly coupled process: numerous steps interact, several hundred sensor signals converge and material properties and operating conditions vary. Until now, quality was measured only by lab sampling, with results available hours later, creating a critical information gap for ongoing operations.

The AI-based functions newly integrated into EVORIS close this gap. They enable early anomaly detection within the process and continuous quality prediction during production. Operators gain a reliable basis to detect deviations earlier, fine-tune the process more precisely and save resources. The fact that the EVORIS suite received the NEO2025 Innovation Award from TechnologieRegion Karlsruhe underscores the significance of this transfer success.

The TAPS unmanned surface vehicle surveying the Ruhr.

Transfer via licensing: Ilmenau expertise for the energy sector
Fraunhofer IOSB also pursues transfer through licensing its technologies to external providers. One example comes from the Cognitive Energy Systems department at Fraunhofer IOSB-AST in Ilmenau: components of the EMS-EDM PROPHET® software suite are licensed to Kraftwerk Software Gruppe and integrated into its new platform for the energy industry.

The technology addresses core processes in an increasingly digitalized energy sector. EMS-EDM PROPHET supports end-to-end workflows such as forecasting, balancing group management, power plant dispatch planning and market communication—capabilities that utilities, grid operators and platform providers must handle securely, scalably and efficiently. Integration into an external platform transfers the technology beyond the immediate project context into broader operational use.

76% more accurate grid-load mapping: For SWE Netz, the error in grid-load modeling for 2024 was reduced from 3.89 GWh to 0.93 GWh.

That the technology delivers tangible benefits for utilities and grid operators is shown, for example, by SWE Netz GmbH. Enhanced data analysis using the WattAnalyzer, newly integrated into EMS-EDM PROPHET, significantly improved their medium-term forecast of electrical grid load (see p. 69). Beyond the forecast improvement, the key outcome for the customer was the ability to use the tool independently going forward.

Piloting autonomous technology in public operations: survey of the River Ruhr
The TAPS project demonstrates transfer into a public-sector application context. Building on the multi-year internal technology development project "Semi-automated survey system for rivers and lakes", we validated an autonomous surveying system in a pilot with the Düsseldorf District Government by mapping an approximately six-kilometer stretch of the River Ruhr under real-world conditions.

The key advance lies in the combination of autonomous data acquisition, compact design and the mapping and navigation software we developed. This made it possible for the first time to collect high-resolution data not only from deep waters, but also from shallow areas and shallow side arms that previous methods could barely capture—or could not capture at all. This significantly improves the data basis for waterway maintenance and flood modeling.

The method provides clear economic and ecological benefits: compared with large, crewed survey vessels or manual measurements, it is

76% more accurate grid-load mapping: For SWE Netz, the error in grid-load modeling for 2024 was reduced from 3.89 GWh to 0.93 GWh.

From left to right: DAKIMO collaborators during a project meeting, AI-based predictions of shared-bike availability at 6:00 p.m. on a Monday in Karlsruhe, and forward-looking routing including shared mobility options in the app.

more cost-effective and significantly less disruptive to near-natural, ecologically sensitive shallow-water zones. At the same time, the software modules developed for mapping and autonomous operation, as well as the resulting 3D models, open up further application opportunities—for example, autonomous surveying of navigation channels, dredging of waterways and, looking ahead, automated logistics chains on water.

Early-stage research with a clear outlook: Sensor protection through computational imaging

Transfer also includes early-stage research that matures into robust demonstrators and protectable intellectual property. SeLaCi, or "sensor protection against lasers using computational imaging," addresses a fundamental challenge for optical sensor systems: intense laser radiation can dazzle cameras or even cause irreversible damage. As lasers gain military relevance, corresponding protection concepts become increasingly important.

Our approach combines targeted defocusing with computational imaging. The core idea is to deliberately shift the image sensor a few millimeters behind the focal plane so that the laser energy is distributed over a larger area and thus causes less damage. In addition, a non-linear optical filter increases the level of protection. The resulting blur is then compensated computationally, restoring a sharp, usable image.

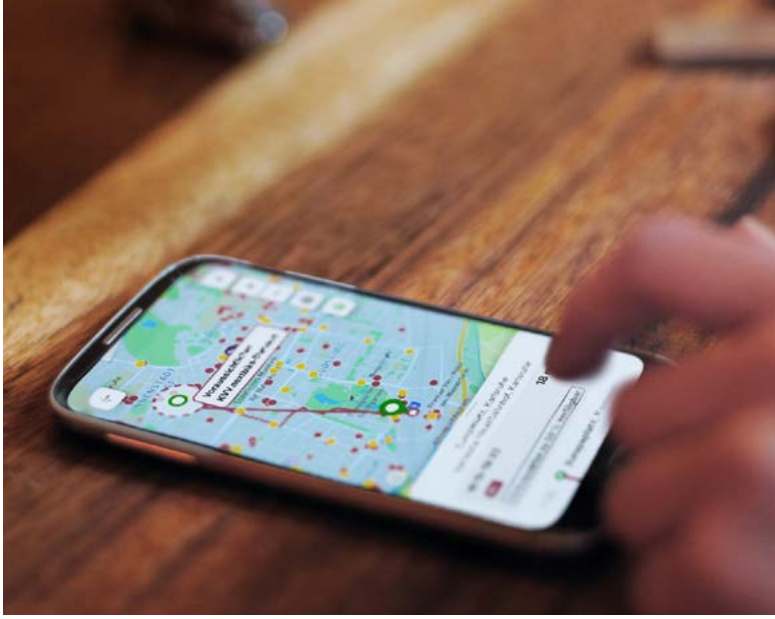
SeLaCi was funded through our internal Technology Development Program (TEP) and involved several departments in Ettlingen and Karlsruhe. After an initial test setup confirmed feasibility and showed that the damage threshold can be increased by several orders of magnitude, a second phase made the system more compact, improved and accelerated image reconstruction, and delivered a functional demonstrator. Patent filings for the setup and the image-generation method show that this has already progressed well beyond a lab result. SeLaCi received the IOSB Innovation Award 2025 as a particularly creative scientific innovation with high market potential.

Standardization as a transfer lever: DAKIMO

The joint project "Data and AI as Enablers for Sustainable, Intermodal Mobility" aimed to make public and environmentally friendly transport modes more reliable, convenient and suitable for everyday use. This requires optimizing cross-modal route suggestions while considering parameters such as weather and expected traffic conditions—using data from a wide range of sources that must be prepared, linked, and evaluated with AI.

One concrete result is an AI-based prediction of the availability of shared mobility vehicles. Based on live and historical data, it calculates the probability of finding a rental bike or e-scooter at a given place and time—improving what has previously been an unreliable transfer point in intermodal routing.

The prediction has already been integrated into a test version of the Karlsruhe Transport Association's regiomove app to inform forward-looking route suggestions. For broader reach, thanks to an initiative advocated by project partner Raumobil, predicted shared-vehicle availabilities are to be incorporated into the General Bikeshare Feed Specification (GBFS), a globally used open standard for real-time



mobility data. This can turn a project-specific AI function into a scalable transfer pathway.

Bringing artificial intelligence into everyday crafts: KIDiHa

The project "Artificial Intelligence and Digital Offensive for the Skilled Trades in North Rhine-Westphalia", or "KIDiHa" in its German acronym, brings AI into small and medium-sized craft businesses. Together with the University of Applied Sciences for SMEs (FHM), the Paderborn-Lippe District Skilled Crafts Association and regional companies, Fraunhofer IOSB-INA in Lemgo develops tools that connect directly to real work processes rather than abstract technology demonstrators.

One example is "StoneCrackMon." When assessing the structural integrity of historic monuments and buildings, the system evaluates acoustic signatures to detect hidden cracks and damage in stone. This makes the expertise of highly experienced stonemasons technically usable and supports less seasoned professionals in inspection tasks. The approach, developed in collaboration with the stonemasonry workshop Diwo, was awarded the Seifriz Prize for its successful transfer of research into skilled crafts practice.

Further applications ease everyday operations: the 'intelligent counter' in a bakery reduces manual cash-register entries and frees up

StoneCrackMon: A microphone captures the acoustic signature of the stone during hammer impact for subsequent AI-based analysis.

Dr. Julius Pfrommer (left) and Andreas Ebner, founders of the Fraunhofer IOSB spin-off o6 Automation GmbH.

time for advice and customer interaction, while in a carpentry shop a voice-based AI solution captures customer requirements and automatically generates a quotation. A new showroom makes these and other hands-on solutions from the KIDiHa project tangible for interested parties.

Spin-off: Professional offerings around an open-source library

With the spin-off o6 Automation GmbH, Dr. Julius Pfrommer and Andreas Ebner, the core developers of open62541, have turned their long-standing expertise into a dedicated offering for industrial practice. open62541 is an open, C-based implementation of OPC UA as a vendor-neutral communication standard for machines, plants, and software in industrial automation. The library is used in products from major automation vendors and was developed in substantial parts at Fraunhofer IOSB.

The spin-off addresses a specific market need: tightened requirements under the Cyber Resilience Act (CRA) create new obligations for commercial users of software libraries, including risk analysis, vulnerability management and development documentation. o6 Automation responds with professional support, consulting, training and customer-specific development.

While open62541 remains an open-source project, o6 Automation offers services and commercial products on this basis. The first of these is o6\Python, an OPC UA implementation for Python, which makes industrial machines and plants accessible from this widely used programming language. This opens up automation tasks to new developer groups, as data scientists and AI experts typically work in Python. In this way, new connections emerge between industrial communication, automation and AI integration.

Generative AI for complex industrial data and processes

The remarkable advances in large language models and generative AI are also shaping our research. Our focus, however, is not primarily on general-purpose text generation, but on complex technical data, industrial standards and concrete engineering tasks in long-standing application domains.

A current example is the **Asset Administration Shell tools FA³ST CreAItor and FA³ST ValidAItor**, released in 2026. Embedded in the modular FA³ST Ecosystem tool landscape, which supports the full lifecycle of AAS-compliant digital twins, they simplify and accelerate digital twin creation and validation by a factor of several. Using available asset information such as a PDF datasheet, FA³ST CreAItor applies a large language model to generate an Asset Administration Shell. FA³ST ValidAItor identifies deviations from the standard and semantic inconsistencies and proposes specific corrections.

In this way, the FA³ST AI tools enable non-experts to create correct and consistent AAS. Easier access to interoperable digital twins lowers the entry barriers, particularly for SMEs, to drive data-driven innovation and leverage AAS-compliant digital product passports.

How generative AI can support concrete engineering tasks in automation is demonstrated by **ChatPLC—LLM-assisted generation of control code for programmable logic controllers (PLCs)**. Fraunhofer IOSB-INA and Phoenix Contact trained a local language model to generate Structured Text (ST) according to IEC 61131-3. In another use case, an AI assistant supports the operation of engineering software. Generative AI thus supports both code generation and the use of development tools.

The whitepaper **"Beyond Text and Images—Generative AI for Diverse Data Worlds"** shows that these examples are part of a broader picture. Published by the Fraunhofer Alliance Big Data and Artificial Intelligence, the paper brings together numerous use cases in domains ranging from industrial production to building and energy management to robotics. Scientists from Fraunhofer IOSB, IOSB-AST, and IOSB-INA contributed to roughly one-third of the cases, highlighting that generative AI can unlock, validate, and operationalize not only text, but also complex technical data structures.

2. Pushing ideas: networking, events, visibility

From dialogue to the construction site of the future: Innovation Day Civil Engineering

The civil engineering sector is under pressure to transform: infrastructure renewal needs, skills shortages, efficiency requirements and new sustainability goals call for solutions that are technologically robust and readily adoptable in practice. Fraunhofer IOSB in Karlsruhe established the Innovation Day Civil Engineering to address this need. At the first Innovation Day, organized in cooperation with the ROBDEKON competence center, around 50 experts from research and industry discussed the automation of construction and heavy machinery, digital twins and product passports, sensor-based sorting and material assessment and experienced these approaches first-hand in live demonstrations.

The Innovation Day topics are echoed in the visIT issue published in parallel, "Technologies for Civil Engineering." The lead essay "Rethinking Road Construction" by Prof. Jürgen Beyerer, also reprinted as a guest commentary in the trade magazine bd baumaschinendienst, outlines a step-by-step vision for a highly automated road construction process. In this way, networking, demonstration and in-depth publication reinforce transfer by linking technological building blocks with concrete development paths.

ROBDEKON as a sustainable platform for exchange, practice and further development

As the competence center's second funding phase approaches its conclusion, we have established a durable organizational structure by founding the association Robotersysteme für Dekontaminationsaufgaben (ROBDEKON e. V.). The association aims to secure ROBDEKON results in the long term, enable sustained exploitation and build a resilient ecosystem spanning research, industry and users. It serves as a point of contact for AI-based robotic systems for decontamination tasks and related technological challenges, promotes research and science, offers continuing-education opportunities and provides a neutral platform for information, opinion and knowledge exchange. The network will be expanded through regular events, practice-oriented workshops and intensive dialogue; organizations and individuals are invited to become members (www.robdekon.de).

RIG: large-scale robotics within the national network

The Robotics Institute Germany (RIG) is creating a nationwide ecosystem for AI-based robotics, aligning research, talent, infrastructures and exchange with industry. As one of three participating Fraunhofer institutes, we focus particularly on large-scale off-road robotics, including autonomous construction machinery, agricultural robots and other heavy machinery for complex tasks in expansive, unstructured environments. With established research expertise and ongoing activities such as ROBDEKON and civil engineering, we are building a hub not only for technological development, but also for shared testing opportunities, practical connectivity and visibility within a major national consortium intended to position German robotics competitively in the global context.

Thinking AI from the perspective of real-world needs

As a founding member of the Baden-Württemberg AI Alliance, we play a leading role in designing and deploying an open infrastructure to enable the sharing of AI assets (datasets and AI models) across multiple application domains and stakeholder groups, built on international standards. We conceived and established the "AI Challenge" as an open networking format designed to bring AI into regional ecosystems, especially for SMEs. Through in-person workshops, the AI Challenge convenes stakeholders from research, business and politics and fosters the joint development of AI project profiles based on user needs, rather than taking a technology-first approach. Its methodological foundation is PAISE®, our established Process Model for AI Systems Engineering.

The autonomous excavator ALICE at the center of attention during a live demonstration, filmed at the Innovation Day Civil Engineering.

ROBDEKON e. V. board: Christian Frey, Dr. Frank Lorenz, Prof. Jürgen Beyerer and Dr. Janko Petereit.

At IAA MOBILITY 2025, Fraunhofer President Prof. Holger Hanselka and members of the press alike showed strong interest in KALLE, Fraunhofer IOSB's research vehicle.

In December 2025, Fraunhofer IOSB hosted the "AI Challenge for the construction sector." Across four thematic tracks—circular economy, resource efficiency, support for construction processes and serial and modular construction—participants developed project ideas and concise concept profiles for follow-on initiatives. After six events, the funded AI Challenge project has concluded. However, the format continues through direct concrete assignments from industry engagements. What began as regional outreach and networking has evolved into an established lasting methodological transfer format building block for AI systems engineering.

Engineering Automation for SMEs

With the Engineering Automation Performance Center in East Westphalia-Lippe (OWL), we are establishing a transfer hub that brings AI into the development of new products and machines. The center is a cooperation between Fraunhofer IOSB-INA (Lemgo) and the Fraunhofer Institute for Mechatronic Systems Design IEM (Paderborn), together with regional universities and companies. It combines generative AI, digitalization and engineering to automate recurring tasks in engineering and industrial IT processes, shorten development times, increase productivity and open new innovation pathways for industrial SMEs. This strategic building block strengthens regional competitiveness and accelerates the transfer of AI into industrial practice.

Trade fairs as a stage for our topics

Alongside the networking formats we (co-)organize, trade fairs remain key platforms for visibility in relevant expert communities. In 2025/26, our departments and business units were represented at CONTROL, LASER, Smart Country Convention, Agritechnica, SPS, E-world, the DWT conference, Xponential Europe, Hannover Messe and AFCEA, among others. A highlight was IAA MOBILITY 2025, where we showcased in-cabin sensing in an accessible and hands-on way on the Fraunhofer joint booth, using the KALLE research vehicle.

KALLE—the Karlsruhe road lab for level 3 evaluation—enables studies of driver and passenger behavior and perception under realistic conditions. It supports connecting a wide range of sensor systems and local analysis on its built-in edge AI computing architecture. At IAA, we presented our AktiMeter software for privacy-compliant activity detection, our work on preventing motion sickness and an approach to studying cognitive distraction.

Where defense research meets the user community

Under the motto "For the armed forces of tomorrow," our Defense Technology Day brings together each year the community we work with in the Defense and Security business unit. In early October 2025, more than 100 project partners, research funders, business customers and users came to Karlsruhe to engage with our colleagues and experience technologies up close. Overview and focus talks covered topics such as high-energy lasers, computational imaging, AI-supported video analysis and cooperative autonomy of unmanned systems. These topics could then be explored directly at exhibits such as SeLaCI (see above), the Digital Situation Table on the web and in VR and laser components developed in-house. In this way, research questions and application perspectives, demonstrators/prototypes and feedback from the user community come together directly in a single day.

Lemgo and Ilmenau: anniversaries highlight a well-established transfer profile

Milestone anniversaries also provide an opportunity to reflect on site development and communicate impact through application-driven growth and effectiveness. In autumn 2024, Fraunhofer IOSB-INA marked its anniversary under the guiding idea "15 years of impact through knowledge transfer." Since 2009, the Lemgo branch has evolved into a technology and science partner for industry and business, consistently aligning its work with practice-oriented automation, connectivity and digital transformation. The anniversary highlights a matured regional role shaped by knowledge transfer.

In 2025, Fraunhofer IOSB-AST likewise framed its 30th anniversary in a programmatic way, with the motto: "Tradition meets transformation." From the outset, the site has been shaped by applied systems engineering research that delivers innovations with concrete benefits for industry and the public sector, for example in energy systems, autonomous work vehicles and underwater robotics.

SmartFactoryOWL: real-world lab with award-winning impact

In April 2026, SmartFactoryOWL in Lemgo celebrated its 10th anniversary. It has established itself as a manufacturer-independent real-world lab and open research and demonstration platform that systematically links research on industrial transformation with implementation in practice. SmartFactoryOWL makes new technologies visible to companies and supports the path from information and demonstration, through qualification, to concrete implementation in practice.

The impact of this successful model is reflected in external recognition. At HANNOVER MESSE 2025, Fraunhofer IOSB-INA received the Factory Innovation Award 2025 in the category Research/Sustainable Factory. The award recognized the Smart-E-Factory project and its approach to reducing resource consumption and CO_2 emissions using AI and direct-current technologies. These solutions are tested and demonstrated in real production environments at SmartFactoryOWL and further developed jointly with companies.

Von Kármán Medal: a NATO distinction with strong signaling impact

Dr. Karin Stein, head of the Signatorics department, received the Von Kármán Medal in 2024 as the first woman in the award's history. The medal is the highest scientific honor of the NATO Science and Technology Organization and recognizes more than 30 years of research and leadership as well as outstanding scientific contributions in the context of the defense alliance. The citation highlights Karin Stein as a scientific bridge-builder between military end users and technical experts. Since 1992, she has contributed her expertise to NATO-STO, led international research groups, served as chair of the Systems Concepts and Integration Panel from 2018 to 2022 and fostered exchange between scientific excellence, technological development and concrete application needs. The medal provides international recognition of her exemplary work, which is also highly influential for Fraunhofer IOSB.

Impressions from an AI Challenge workshop: stakeholders from research, business and politics jointly developing AI project profiles based on user needs.

Interview with Karin Stein:

3. Organizational development and infrastructure

The humanoid robot Ophelia (Optronic Proactive Human-AI Explainable Interaction Assistant) at Fraunhofer IOSB Karlsruhe during unboxing.

Scenes from Doctoral Candidates Day.

A lab between experimentation and application

With the Humanoid Robots Experience Lab, Fraunhofer IOSB is establishing an open environment for testing, demonstration and hands-on evaluation of humanoid robotic systems. The objective is not to develop our own humanoid or legged platform, but to conduct evaluation, integration, safety and transfer research. The focus is on questions that are decisive for future productive use: Where do humanoid robots add value? How can such systems be deployed across domains, from industry to municipal services to construction and civil security? And which capabilities are still missing for robust, dependable applications?

To this end, we are currently developing a cross-site lab with a shared brand and site-specific thematic focal points. In Karlsruhe, Lemgo, and Ilmenau, one Unitree G1 EDU 3 system is already available at each site; additional humanoid platforms are planned. Access is deliberately designed to be easy: simple demonstrators make potential, limitations and use cases directly tangible and support a realistic assessment of the technology.

Together with users, this can be translated into concrete use cases, initial pilot ideas and dedicated solutions for specific operational scenarios. In this way, we create value-oriented options for our customers in a highly dynamic field while systematically building a sustainable research profile in humanoid robotics—addressing topics characteristic of Fraunhofer IOSB ranging from environmental perception and autonomy to manipulation, interaction and collaboration in mixed human-robot teams. At the same time, practical experimentation provides realistic insights into capabilities, safety aspects and application perspectives that cannot be reliably assessed otherwise.

Sharpening business units, developing transfer more strategically

Across its business units, Fraunhofer IOSB consolidates cross-departmental competences into a structure that is easier for companies, public clients and cooperation partners to understand and engage with. As part of a scheduled review, industrial advisors reassessed the business units in 2024, resulting in further development and minor shifts in emphasis. Since 2025, our five business units have been: Automation and Digitalization; Energy, Material Cycles, and Crisis Management; Advanced Sensing; AI and Robotics; and Defense and Security (for details, see the chapter "Business Units").

The business units remain rooted in the respective scientific departments involved, from which the business unit spokespersons are elected. This structure is complemented by the newly defined role of Business Developers, who work across departments and sites. They connect technical development with market outreach, internal and external networking, and help drive development and acquisition. In doing so, they form a robust interface between scientific expertise and concrete application demand—where topics are sharpened, contacts are developed and transfer opportunities are translated into projects. Detailed profiles of the four current Business Developers can be found on the following double-page spread.

Strengthening networking for early-career researchers in a targeted way

Doctoral candidates are often insufficiently visible in day-to-day institute life and have limited interaction across departmental boundaries. At the same time, they face a particular need for guidace while balancing scientific qualification and project-oriented work within the Fraunhofer model.

The Doctoral Candidates Day therefore creates a dedicated space for networking as well as professional and personal development across research areas. The program combines short scientific pitches with workshops on practical topics and an open discussion with institute management. In this way, the format strengthens cross-departmental exchange, provides orientation and supports the long-term development of early-career researchers as an integral part of the institute's scientific profile.

Reliable structures for impactful research
To ensure that research, projects and transfer remain viable in the long term, we are systematically strengthening the organizational foundation of the institute. Since 2026, quality management has been established as a regular sub-unit within the institute's Staff department, with the objective of continuously improving structures and processes. Clear and readily accessible process descriptions ensure transparency in daily operations, clarify responsibilities and reduce coordination overhead across research administration and project execution. Complementing this, the Continuous Improvement Process (CIP, German: KVP) according to DIN EN ISO 9004:2018 "Quality management—Quality of an organization—Guidance to achieve sustained success" provides a structured mechanism for capturing improvements from day-to-day work and translating them into concrete changes. Designed for small, directly implementable steps, the CIP is supported by an intranet dashboard that transparently displays the status of proposals and implemented measures.

Karlsruhe and Ettlingen have been certified since February 2026; Ilmenau and Lemgo are currently undergoing the audit process.

A visible milestone in this development is the successful certification of the Karlsruhe and Ettlingen sites according to DIN EN ISO 50001:2018. Beyond professional energy management, it stands for an organization that addresses requirements systematically, anchors responsibility clearly and can reliably demonstrate improvement. The continued development of information security and data protection management follows the same logic. In doing so, we also create the conditions to fully meet current and future regulatory requirements. Reliable standards, clear roles and auditable procedures create the institutional maturity that underpins demanding collaborations, sensitive projects and sustainable long-term transfer.

Spaces for the next development phase
With the Karlsruhe Research Campus, a long-term infrastructure foundation for the next development phase is being created on Fraunhofer IOSB's premises in Karlsruhe. The concept—revised and further specified compared to the competition-winning design—has been approved; the building application is close to finalization and the start of construction is expected for early 2027.

Two additional buildings on the institute campus will in the future host the Fraunhofer Institute for Systems and Innovation Research ISI, which has a social-science orientation. This opens up new opportunities to connect the work of both institutes, particularly with regard to the responsible development and application of AI and autonomous systems, including their economic and social implications. In addition, new modern office and lab space will be created for Fraunhofer IOSB. Organizational development thus gains a visible physical dimension—an investment in the conditions under which research and transfer can continue to grow sustainably.

Final design of the new building in Karlsruhe. Top: the new Fraunhofer ISI main building; the existing IOSB south wing is visible on the right. Bottom: view of the new building from the east.

Four Business Developers, four thematic axes

Automation and Digitalization

M. A. M. Eng. Nissrin Heymann

She addresses key fields of action at the interface of our service portfolio, the market and strategic development, with a focus on infrastructure services automation mainly on the field level, processes, AI and robotics and internationalization. Her work includes expanding test-before-invest offerings, increasing the visibility of research infrastructure-based services, strengthening international partner outreach and developing aligned offerings for new robotics and AI topics. With many years of experience in research and transfer in Lemgo and a long-standing role in SmartFactoryOWL, she brings deep practical knowledge of how transfer formats can be tailored to specific target groups and regional innovation ecosystems.

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Tel. +49 5261 94290-93

Automation and Digitalization

Dr.-Ing. Olaf Sauer

He connects business unit coordination, business development, marketing, sales and acquisition activities within the business unit Automation and Digitalization. His work includes further developing the business unit's content, supporting the Karlsruhe Research Factory, contributing to expert committees and networks and directly engaging with industry, ministries and project management agencies. Having coordinated the business unit since 2010 and built a long-standing presence in bodies such as VDI, Smart Electronic Factory e. V. and other Industry 4.0 networks, he strongly embodies the institute's roots in the industrial digitalization community.

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Tel. +49 721 6091-477

AI Systems Engineering

Dr.-Ing. Thomas Usländer

He drives AI Engineering as a strategic future topic for the institute, working across departments, business units and sites. His focus is on the systematic development and operation of AI-based solutions, the establishment of partner ecosystems and the alignment of methodology, tools, regulation and concrete transfer formats. With a long-standing background in IOSB's Information Management and Production Control department and as head of the competence center Karlsruhe for AI Systems Engineering (CC-KING), he now also leads two central initiatives of the Baden-Württemberg AI Alliance, the AI Challenge mentioned above and the AI Data Platform.

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Tel. +49 721 6091-480

Advanced Sensing

Dipl.-Ing. Dirk vom Stein

He develops the business unit Advanced Sensing from a strong application perspective, combining business development with close proximity to the market. Expert events, matchmaking, demonstrators and concrete use cases help translate contacts more quickly into robust problem statements, offers and business unit development. His perspective is shaped by 25 years of experience in automated visual inspection for automotive suppliers, especially foundries, giving him a particularly strong understanding of customer requirements, industrial constraints and application realities.

dirk.vom.stein@iosb.fraunhofer.de
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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 reflected in the institute's name.

Following several adjustments to the departmental portfolio in previous years, there have been no further additions or renamings of departments since 2024 (see organization chart, pp. 26–27). Leadership has changed in two departments: Dr. Constanze Hasterok, formerly a group manager, has taken over as head of the Cognitive Industrial Systems department, following the departure of Dr. Julius Pfrommer to our spin-off o6 Automation. Florian Pethig, previously a group manager in the Machine Intelligence department in Lemgo, has become head of the department, succeeding Dr. Oliver Niehörster, who has taken on a new role at iplus1, a company he co-founded.

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, a Chair in Collaborative Robotics at Bielefeld University 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

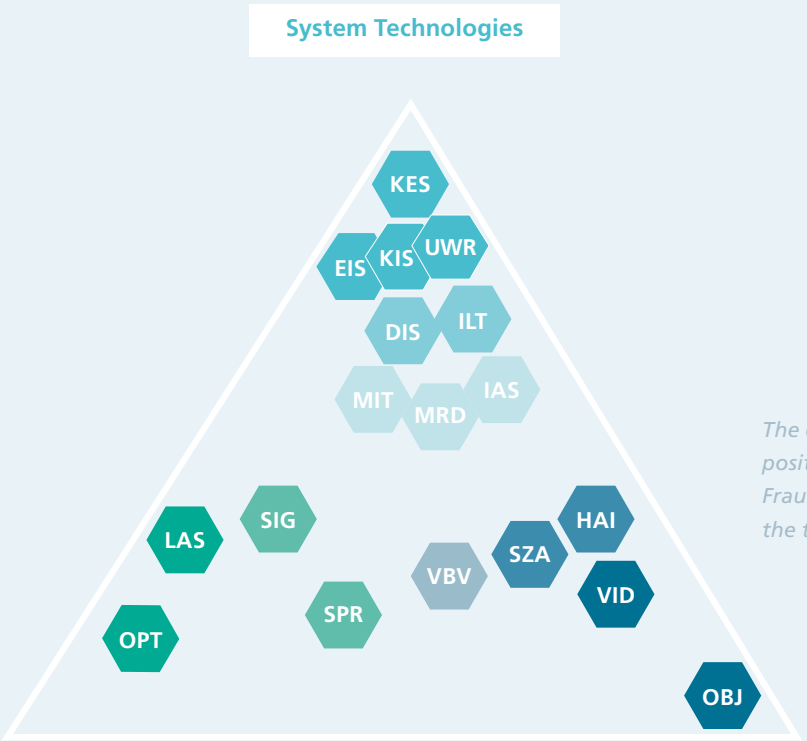
- Cognitive Energy Systems | KES
- Cognitive Industrial Systems | KIS
- Digital Infrastructure | DIS
- Embedded Intelligent Systems | EIS
- Information Management and Production Control | ILT
- Interoperability and Assistance Systems | IAS
- Machine Intelligence | MIT
- Systems for Measurement, Control 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 our clients' commercial success, we provide services, components and complete systems based on a broad spectrum of technologies, methodologies and expertise. Developing best-in-class solutions requires not only excellent scientific and technical skills, but also a deep understanding of industry needs.

Three funding pillars enable successful research

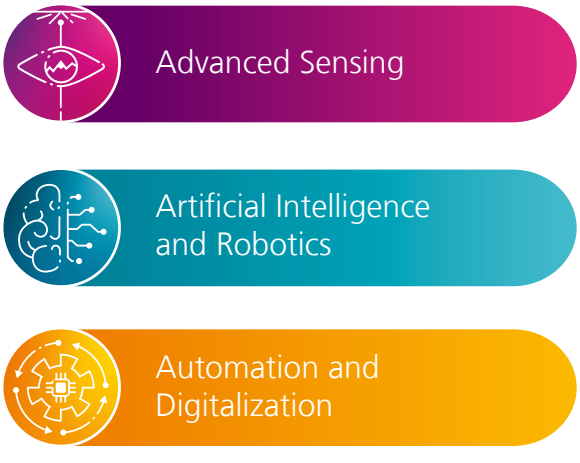
As an institute committed to applied research, we source roughly a third of our budget from projects with clients across a range of industries, including private-sector companies as well as public-sector bodies such as municipalities and environmental or security agencies. Another good third comes from publicly funded research projects, in which we often collaborate with companies, other application partners and research organizations.

These collaborations keep us in continuous dialogue with a wide range of partners and help us deepen our applied expertise across diverse domains. This, in turn, enables us to pursue highly relevant, potentially disruptive research and technological innovation. It also allows us to make effective use of the remaining share of our funding, which is provided as base funding.

Serving specific market needs: our business units

Our business units are the focal points where we concentrate our expertise in specific application domains. They develop solutions, services and products tailored to the needs of their respective markets. The departments described above define our organizational structure. The business units, by contrast, form an additional layer superimposed on this structure and aligned with the markets we address. Departments contribute their expertise through the individual business units to serve these markets.

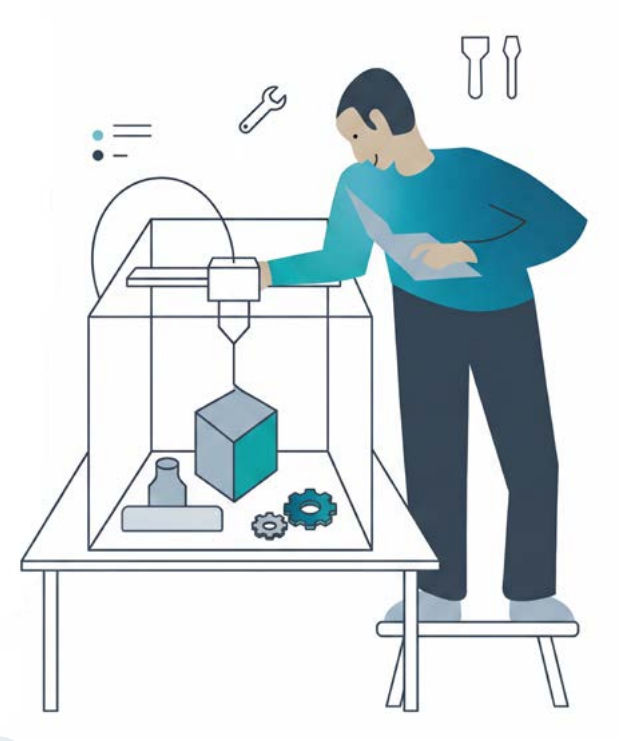
Business units



Our business units transfer research results into practical applications to address future challenges. Close dialogue and collaboration within our business units and with partners across the business community enable us to leverage synergies effectively.

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

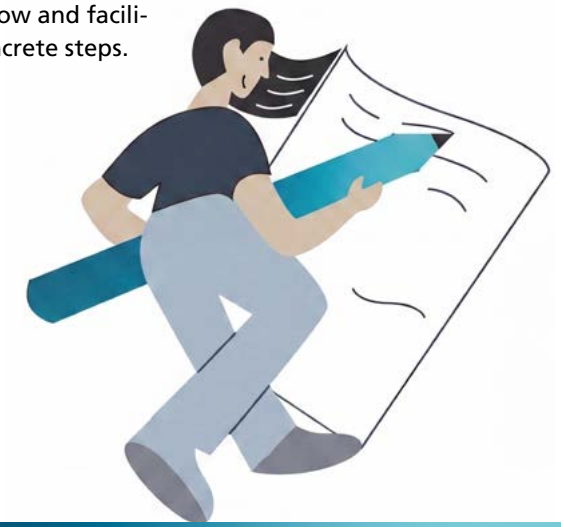
How to cooperate with us



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 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 potential 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.

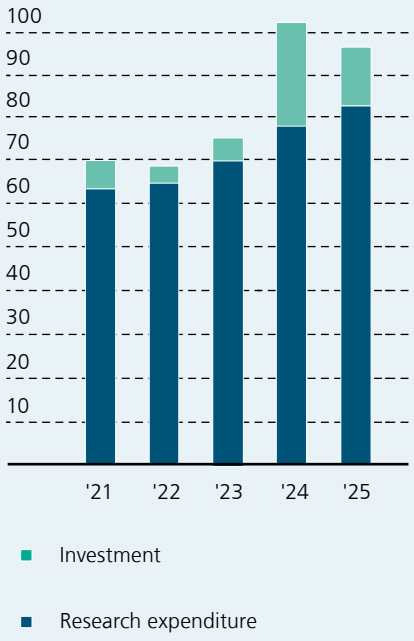
Tailored to your needs

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

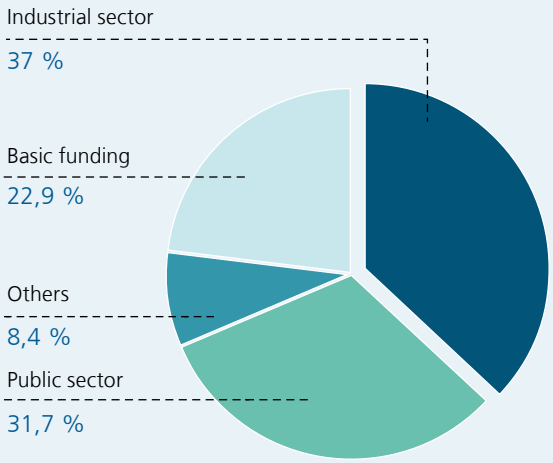
Business expenses

How much money did we spend?



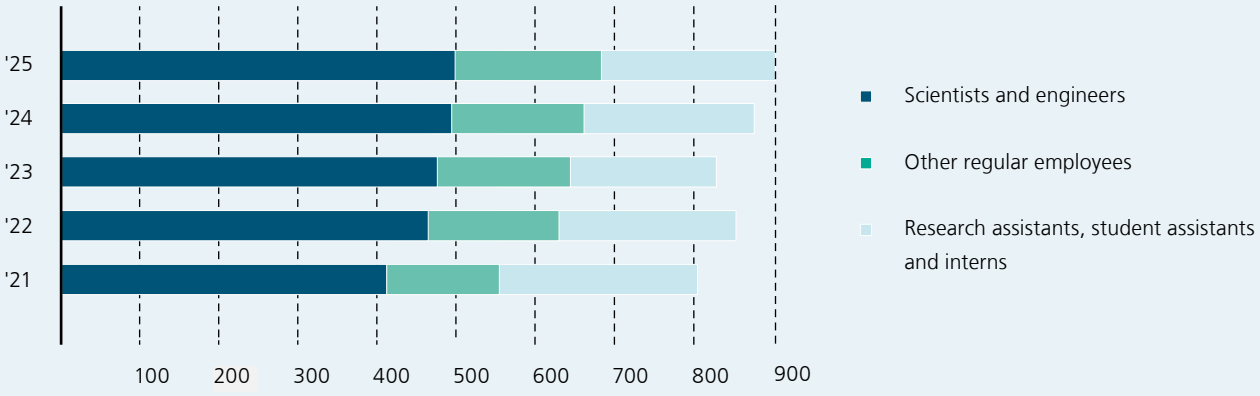
Funding

Where did the money come from (in 2025)?



Staff

How many persons worked at Fraunhofer IOSB?



Organization chart

Heads of institute
Prof. Dr.-Ing. habil. Jürgen Beyerer (Executive Head), Prof. Dr. rer. nat. habil. Marc Eichhorn

Board of directors
Prof. Dr.-Ing. habil. Jürgen Beyerer
Director Karlsruhe

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

Deputy

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. rer. nat. Constanze Hasterok

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

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

Prof. Dr.-Ing. Jürgen Jasperneite
Director Lemgo

Ilmenau

Advanced System Technology branch Fraunhofer IOSB-AST

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

DIS | Digital Infrastructure

Dr.-Ing. Sebastian Schriegel

MIT | Machine Intelligence

M.Sc. Florian Pethig

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

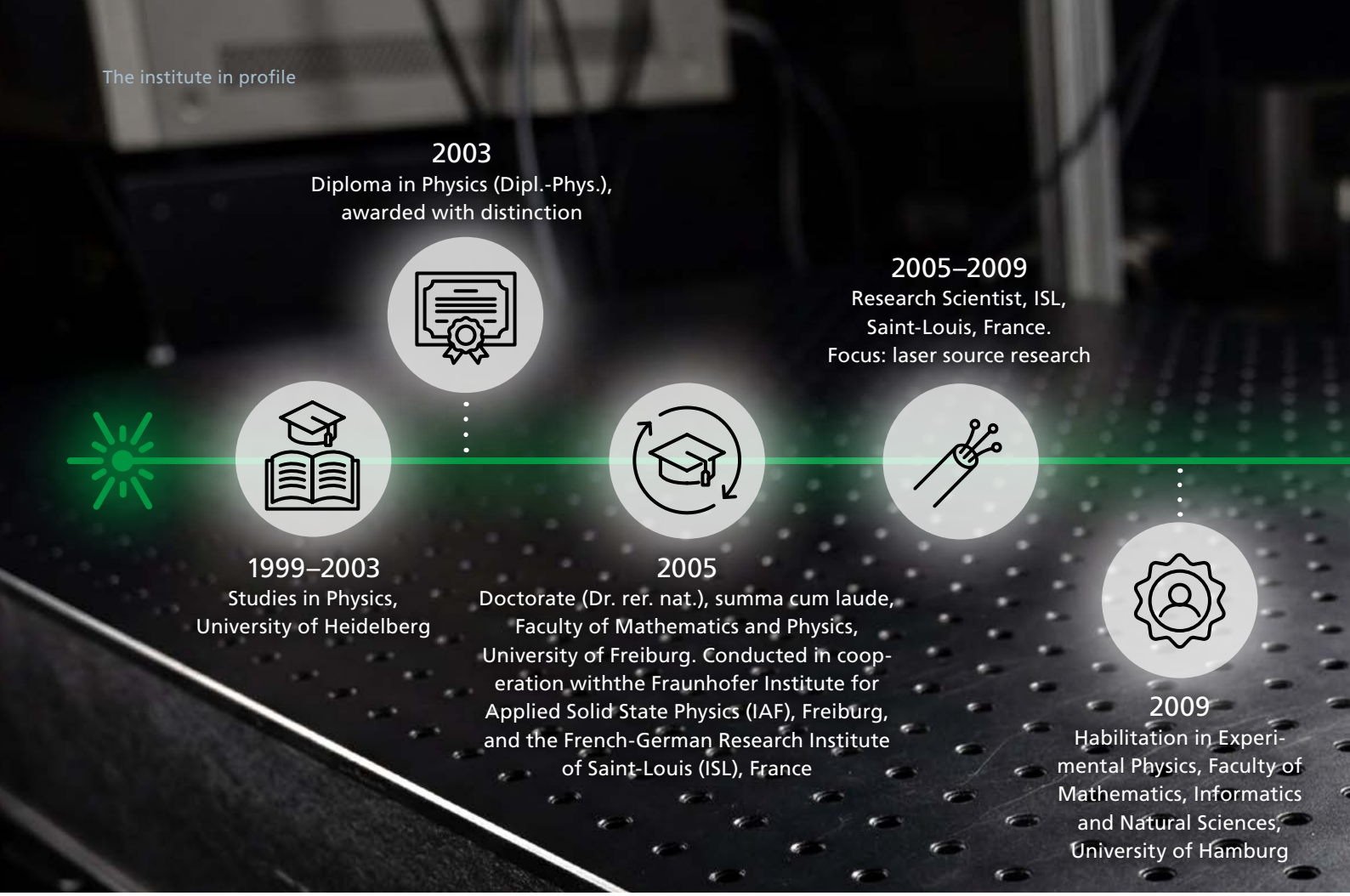
Staff department

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



Leadership shaped by expertise

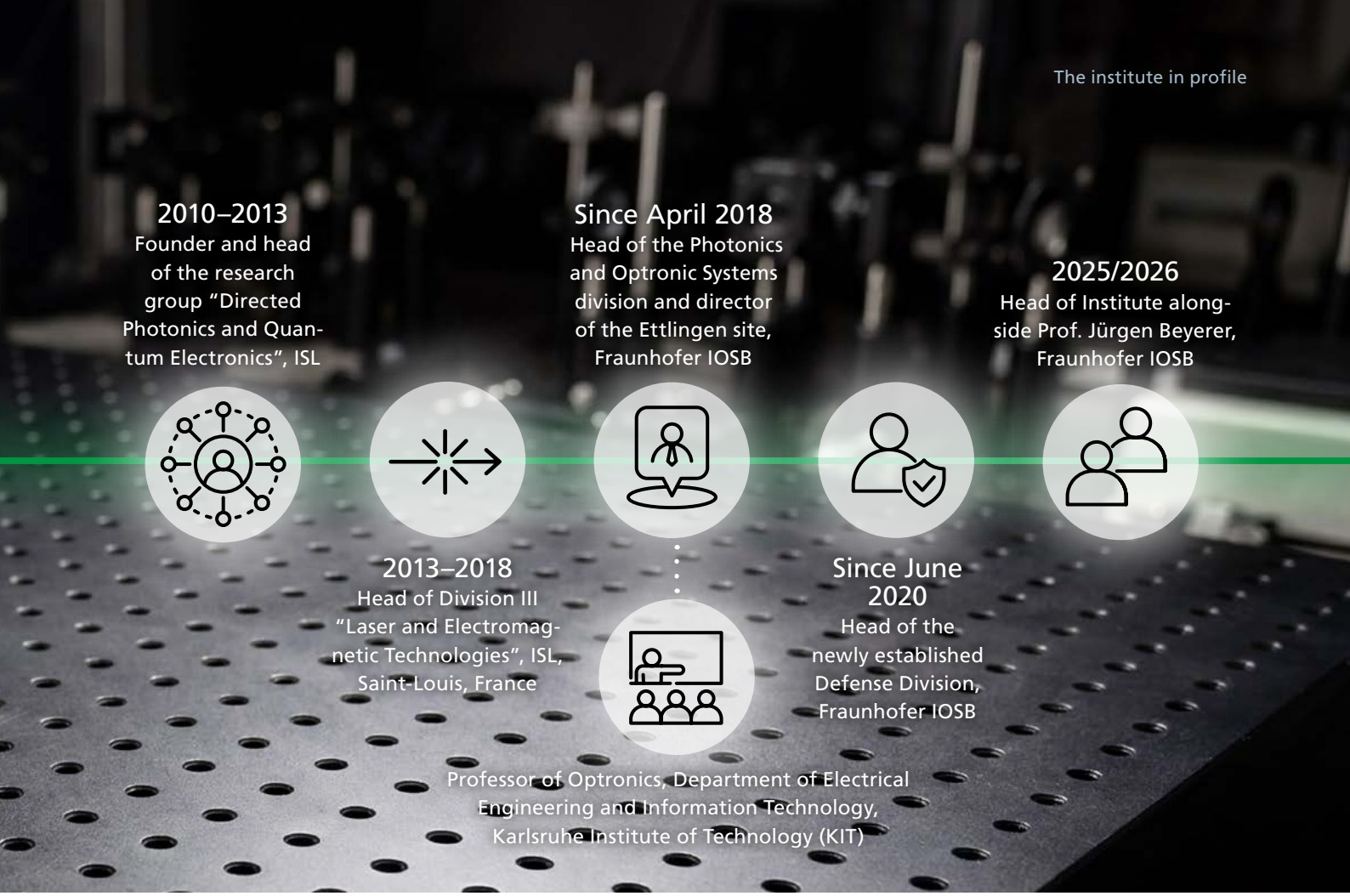
With Prof. Marc Eichhorn joining Prof. Jürgen Beyerer as Head of Institute, Fraunhofer IOSB has expanded its institute leadership. Eichhorn's work since 2018 shows how scientific expertise, strategic development and institutional responsibility come together.

The new leadership constellation reflects how our competence profile has evolved in recent years. Since joining Fraunhofer IOSB in 2018 as Head of the Photonics and Optronic Systems division and Head of the Ettlingen site, Marc Eichhorn has contributed to this evolution by extending our optronics profile toward light generation itself. Building on IOSB's established expertise in imaging, detection and information processing, he has added an important new dimension: laser source research and the technologies needed to generate and amplify light.

This contribution is rooted in Eichhorn's scientific background as much as in his ability to turn new fields of research into institutional structures. After many years of laser source research at the French-German Research Institute of Saint-Louis, he brought deep expertise in laser physics, along with a clear understanding of how this expertise could complement our existing strengths. The result has been tangible institutional development: a laser technology department, new research infrastructure for high-energy lasers, crystal growth and crystal processing, and the continued development of the Ettlingen site.

Eichhorn's work has also had an impact beyond Ettlingen. In 2020, he took on responsibility for the newly created Defense Division and helped strengthen defense-related research across the institute, including the extension of basic funding from the German Federal Ministry of Defense (BMVg) to departments in Karlsruhe. Eichhorn also helped initiate the new Oberkochen site devoted to the realization of active fiber preforms and fibers for fiber lasers, and helped secure start-up funding for the site.

His role in institute leadership builds on a profile that combines research, management, communication and the ability to



create structures in which others can advance their work. In this role, he will contribute to further developing Fraunhofer IOSB's expanded competence profile and to creating the conditions in which new fields of research can grow into lasting institutional strengths. Together with KIT and with partners in Germany and abroad, this work will help strengthen Baden-Württemberg as a leading center for optronics and related laser systems and support Germany's technological sovereignty in fields of growing strategic relevance.

Laser physicist Prof. Marc Eichhorn has shaped Fraunhofer IOSB in roles including divisional director Defense and director of the Ettlingen and Oberkochen sites. He also holds the Chair of Optronics at Karlsruhe Institute of Technology (KIT).

Pooling expertise across Fraunhofer

Fraunhofer's strength lies not only in the expertise of its individual institutes, but also in the way this expertise is connected across the organization. As part of Europe's leading applied research organization, Fraunhofer IOSB contributes its capabilities in optronics, system technologies and image exploitation to this network.

With 74 institutes and research units, more than 30,000 employees and an annual research volume of 3.2 billion euros, Fraunhofer has the breadth to address complex technological challenges—from digital value creation and circular economy to security, resilience and climate-neutral energy systems. Fraunhofer IOSB participates in this community through complementary formats: discipline-based groups, market-oriented alliances, strategic clusters and regional high-performance centers. These structures help combine expertise across institute boundaries and accelerate transfer.

Fraunhofer Groups and Segment

Fraunhofer Groups bring together institutes with related scientific and technological profiles, enabling them to act jointly on the R&D market and develop cross-industry system solutions. Fraunhofer IOSB is involved in:

- Fraunhofer ICT Group
- Fraunhofer Group for Light & Surfaces (guest member)
- Fraunhofer Group for Energy Technologies and Climate Protection (guest member)
- Fraunhofer Segment for Defense and Security VVS

Fraunhofer Alliances

Fraunhofer Alliances pool expertise for specific industries and application domains. They provide clients and partners with coordinated access to interdisciplinary solutions. Fraunhofer IOSB participates in:

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

Fraunhofer Clusters of Excellence (CoE)

Fraunhofer Clusters of Excellence operate as virtual institutes for strategic, system-relevant fields of technology. They follow long-term roadmaps and bring together complementary competences from across Fraunhofer. Fraunhofer IOSB participates in:

- Fraunhofer CoE Integrated Energy Systems CINES
- Fraunhofer CoE Cognitive Internet Technologies CCIT
- Fraunhofer CoE Circular Plastics Economy CCPE

High-Performance Centers

High-Performance Centers create regional innovation ecosystems by linking Fraunhofer institutes, universities, higher education institutions and other research partners. Fraunhofer IOSB is involved in:

- Karlsruhe Mobility — KAMO
- Intelligent Signal Analysis and Assistance Systems — InSignA, Ilmenau
- Engineering Automation, East Westphalia-Lippe

Beyond these formal structures, Fraunhofer IOSB cooperates with sister institutes wherever complementary expertise is needed—ensuring that clients and partners can draw on the full breadth of Fraunhofer capabilities.

The Fraunhofer-Gesellschaft at a glance

3.2 billion
euros of revenue from contract research each year

... more than two-thirds of which is raised competitively from private-sector contracts and public project funding

Over
30,000
employees

In 2024, the share of women in research staff rose to 24.5 percent. Women accounted for around 30% of newly recruited scientists.

74
institutes

... organized into nine groups.

2
patent applications every workday

Fraunhofer ranks first among European public research institutions in patent applications.

Over **90%**
of our institute directors hold a professorship

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

Over
500
charging points for electric cars

The Executive Board of the Fraunhofer-Gesellschaft has set the target of a 55% reduction in greenhouse gas emissions by 2030 (baseline year: 2019).

Approximately
30
spin-offs per year

... over 500 since 2000. Roughly 85 percent are still active after ten years.

Over
7,000
active patent families

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

Real innovations.
#WeKnowHow

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

Amid shifting geopolitics, rising terrorism, and more frequent natural disasters, robust defense and security research is more vital than ever. We develop technologies, products and services that detect threats early, enable effective countermeasures, and minimize harm—reducing overall risk.

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 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
Prof. Dr.-Ing. Peter Knott, Fraunhofer FHR

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

Managing director
Dipl.-Ing. Caroline Schweitzer
caroline.schweitzer@vvs.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.

We offer solutions for:

- computational imaging, including light field technologies, compressed sensing, lensless imaging
- laser sources and laser systems
- innovative optronic components
- inspection and remote sensing systems
- system technology through to prototypes in use

Advanced Sensing

Contact

Spokesperson
Prof. Dr.-Ing. Thomas Längle
Phone +49 721 6091-212

Business developer
Dirk vom Stein
Phone +49 721 6091-524

Departments involved

- LAS
- OPT
- SIG
- SPR
- SZA

We make the invisible visible and develop innovative imaging systems together with our customers—from the initial concept to the prototype.

In this business unit, we combine our expertise in advanced sensor technologies ranging from hyperspectral sensors to laser systems. We integrate state-of-the-art sensor technologies, optical measurement methods and automated data evaluation for customized, highly precise results.

Our main areas of focus include laser communication in free space, light field technology for directional displays, and precise detection and inspection systems. We offer solutions for the contactless measurement and quality control of complex components embedded in production processes in the automotive and consumer goods industries. We use drones and long-range sensors to monitor both the environment and critical infrastructures such as wind turbines and pipelines.

www.iosb.fraunhofer.de/ads

Hybrid lighting is not about replacing LEDs, it is about using sunlight as a controllable resource indoors«

Hybrid lighting systems developed by Fraunhofer IOSB show how sunlight can be collected, shaped, and used efficiently indoors—from farming to buildings.

Prof. Längle, indoor farming promises efficiency and resilience, yet lighting remains a major bottleneck. Why?
Lighting drives both electricity demand and heat load. In Future Proteins, a Fraunhofer flagship project on closed cultivation systems for alternative protein sources, we explored hybrid lighting to make indoor plant production more efficient than artificial light alone. Even modern LEDs still convert the major part of the supplied electrical energy into heat, and that heat must be removed to keep the cultivation environment stable. Lighting therefore consumes energy twice: directly for illumination and indirectly for cooling.

What does "hybrid lighting" mean in this context?
It is more than simply adding daylight to LEDs. Our system collects sunlight over a larger area, guides it into a compact optical path, separates it spectrally, transports it through fibre bundles, and mixes it with artificial light in a controlled way. A key advantage is that infrared radiation can be removed before the light enters the indoor system. This makes it possible to use the visible part of sunlight while keeping much of the unwanted thermal load out—or redirecting it to other purposes.

What has Fraunhofer IOSB demonstrated in practice?
The project delivered a working proof of concept. Fraunhofer IOSB developed and integrated a hybrid lighting system including sunlight collection, fibre coupling, light transport, mixing, spectrometric monitoring, and control of the spectral composition. It also enables light recipes, meaning the spectral mix can be adapted to specific needs. At the same time, Future Proteins and related work showed that, while clearly superior in terms of physical efficiency, hybrid lighting does not automatically pay off economically under current conditions.

So beyond vertical farming, where do you see potential?
Wherever high-quality indoor lighting is needed but conventional daylight access is limited—or where daylight brings too much heat into the building. That includes factory halls, office buildings, museums, and windowless retail areas. In such settings, hybrid lighting could help reduce dependence on purely artificial illumination while improving light quality and easing the cooling burden that usually comes with large glazed areas or high lighting loads. Sunlight offers a full-spectrum white light that artificial systems do not reproduce in the same way. Hybrid lighting opens up a new option: using daylight indoors while decoupling illumination from thermal load. That is why the idea matters not only for agriculture, but for indoor environments more broadly.

**Prof. Dr.-Ing.
Thomas Längle**

Business unit spokesperson
Phone +49 721 6091-212
thomas.laengle@
iosb.fraunhofer.de

Artist's impression of the future LMT ground station.

Project ADAMO: high-power adaptive optics for laser momentum transfer

More than 22,000 space debris objects in low Earth orbit (LEO) are currently being tracked and catalogued. In the same orbital regime, there are an estimated 150 million fragments of human-created junk, all smaller than 1 mm, travelling at around 7–8 km/s. This highlights the pressing need for effective solutions to address space situational awareness, tracking and imaging of space objects, collision avoidance and, ideally, space debris removal.

One option for removing space debris is to nudge it by photon pressure, generated by high-power continuous-wave lasers (>10 kW). This laser momentum transfer (LMT) has a significantly smaller effect compared to laser ablation by high-power pulsed lasers, but by combining a greater number of laser stations, it becomes a viable option.

As part of the ESA-funded project ADAMO, Fraunhofer IOSB, IOF and University of Applied Sciences Western Switzerland are developing demonstrators for adaptive optics (AO) technologies that are necessary to efficiently pre-compensate high-energy lasers in order to make LMT effective in low Earth orbit.

The project's key objectives are to design an AO system capable of compensating for the quickly changing wavefront distortions induced by atmospheric turbulence and telescope slew. The future system will utilize a laser guide star for sensing high-order aberrations and sunlight reflected from debris for low-order aberrations. The project will also involve the development of a demonstrator to validate the key AO system's functionalities in a controlled laboratory environment.

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Visible damage to optical components produced and detected by the ELIDT measuring system.

ELIDT: damage threshold measurement and ellipsometry in one system

The objective of the internally funded ELIDT (Enhanced Laser-Induced Damage Threshold) project is to develop a fully integrated measuring system that combines damage threshold measurement and ellipsometry to perform precise tests of optical components and coatings on both flat and curved surfaces. One unique feature of this system is that it can be used in-house, allowing test processes to be directly integrated into corporate workflows.

In 2025, we reached a number of important milestones: We finished developing a stable, high-performance, eye-safe solid-state laser source at 2 µm. This laser has been optimized with particular attention to pulse energy and stability in order to guarantee reliable results. We integrated an ellipsometer capable of detecting damage on freeform surfaces and validated the system's functionality by means of laboratory measurements. We also developed a software application to automate the measurement process, thus making the system more efficient and easier to operate.

The Laser Technology department in Ettlingen and the Visual Inspection Systems department in Karlsruhe worked in close collaboration to drive these advances. In 2026, we will focus on building and testing the first prototype. We intend to continue validating the system's functionality and finalize the automation so that we can offer a reliable solution for optical measuring technology.

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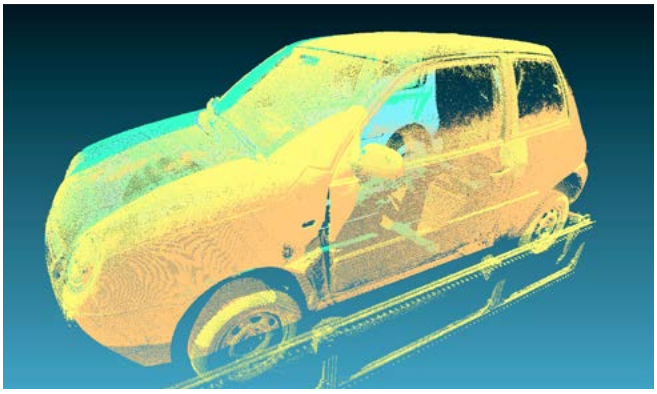

Combined 3D point cloud generated from four triangulation modules.

SKaLEV Self-calibrating laser line triangulation for the 3D measurement of large objects

Laser line triangulation can be used to obtain high-resolution 3D measurements at comparatively low cost when performing quality control procedures during production cycles. However, when large objects have to be measured from different sides using multiple sensor modules, the accuracy of the measurements is usually limited by the mechanical stability of the calibration.

Not so with the self-localization concept developed at Fraunhofer IOSB: This eliminates the role played by factors such as the mechanical stability of the supporting structure and sensor mounts and the extrinsic calibration of the sensor system as a whole.

Each line laser and each connected triangulation sensor is equipped with an additional so-called pose camera for this purpose. These cameras register a marker arrangement mounted on the carrier platform of the object being tested. The system can then pinpoint the laser plane and the viewing direction of each sensor independently within the object's coordinate system every time a measurement is taken. It then uses the laser line image projected onto the object to compute a 3D profile. When the object carrier or the sensor components are moved, the profile data from any number of triangulation modules are correctly combined to form a complete 3D surface model of the object. This can then be compared with a nominal CAD model, for example.

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Series of measurements with the PHENOBox at a vineyard operated by the Julius Kühn Institute for Grapevine Breeding.

SmartViticulture: intelligent image processing for the agriculture of the future

Agriculture is facing major challenges as a result of climate change and labor shortages. Fraunhofer IOSB is now developing innovative viticulture solutions as part of the internally funded SmartViticulture project. However, the potential of these solutions goes far beyond wine-growing.

The core of the project is PHENOBox HSI, an intelligent image processing system that registers physiological plant traits such as ripeness, sugar content and drought stress in real time. What makes it unique is the use of AI-supported adaptive radiometric correction that automatically adjusts to changing light conditions—a breakthrough for use in real-world environments. Developed by a cross-departmental research team, the system combines ground-based and aerial hyperspectral imaging. While drones provide large-scale overviews, mobile camera systems capture detailed information at the level of individual plants. These complementary approaches allow precise analyses to be performed in a way that has not been possible until now.

This technology has a wide range of potential applications: Institutes such as the Julius Kühn Institute for Grapevine Breeding use it for phenotyping new varieties of grapevine. Agricultural machinery manufacturers can potentially integrate it into autonomous harvesting systems and robotic platforms. Growers benefit from accurate decision-making tools when making decisions about irrigation, fertilization and selective harvesting. Thus, with SmartViticulture, we are positioning ourselves as competent partner in AI-supported image processing for precision agriculture, a key technology for sustainable food production.

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We offer solutions for:

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- AI engineering, process optimization
- data analysis, image evaluation and environmental representation

Artificial Intelligence and Robotics

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- KIS
- MRD
- MIT
- UWR
- VID

From basic questions to embodied AI

The Artificial Intelligence and Robotics business unit conducts applied research throughout the field of artificial intelligence and machine learning. We offer our partners and customers extensive methodological and applied expertise not only in deep neural learning but also in many other areas.

We focus on basic questions such as algorithmic transparency, explainability, integration of expert knowledge and AI engineering. We also develop solutions for specific applications. These include environmental sensing and diagnostic and adaptive learning systems as well as solutions for localization and motion planning, behavioral analysis, data analysis and reasoning, anomaly detection, decision support, knowledge representation and human-AI interaction. Another focal area of our 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.

The Artificial Intelligence and Robotics business unit 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 collaboration with other business units.

www.iosb.fraunhofer.de/air

Robust AI emerges where simulation and reality are brought together systematically«

By enabling a comprehensive representation of relevant scenario diversity, simulation and synthetic data are becoming key enablers for AI systems that are both safe and viable in real-world environments.

Dr. Voit, why is synthetic data gaining so much importance right now?
Today, many AI systems fail not because of algorithms, but because of the limits of available data. In safety-critical domains, rare or privacy-sensitive situations are difficult to capture in real-world data. Simulation and synthetic data help to close this gap by enabling relevant scenarios to be generated, varied and used for training and testing under controlled conditions. As a result, the focus is shifting from pure data collection towards strategic data development.

What does this mean from the perspective of the AI and Robotics business unit?
We develop AI systems for real, dynamic environments. These systems must operate reliably even under changing weather conditions, incomplete sensor data or unexpected behavior by other actors. In simulations, such parameters can be varied systematically to generate training and test data. At the same time, we are aware that a domain gap often exists between simulation and reality. For this reason, we combine virtual data with privacy-preserving real-world data. This creates a feedback loop in which real observations improve simulation, while simulation in turn helps make AI systems more robust.

Where does Fraunhofer IOSB come in?
Across the entire chain from data acquisition to application. With OCTAS® (see p. 83), we are developing an open, modular simulation platform for autonomous mobility systems. It supports not only virtual validation, but also the generation of synthetic datasets. In AVEAS (see p. 42), we have demonstrated how critical traffic situations can be captured in a privacy-compliant manner and transferred into data-driven simulation environments—including behavior, dynamics and sensor models. This transforms isolated datasets into a transparent, reproducible basis for developing and testing AI systems.

What added value does this offer for industry and users?
A good example is our AktiMeter, a system we developed for intelligent in-cabin behavior analysis. It enables real-time analysis of body poses, gestures and activities inside the vehicle for applications such as user research, ergonomics or adaptive assistance systems. Early development stages were based on driving simulator data; today, it is close to market readiness. While new approaches such as Vision Language Models are emerging that require less task-specific training data, reliable testing and validation remain essential—where simulation and synthetic data are key instruments.

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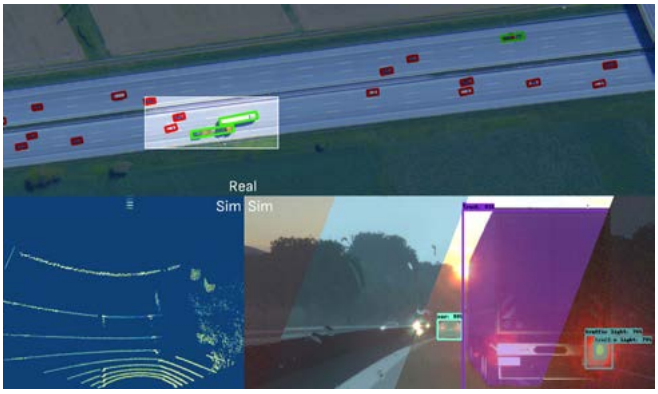
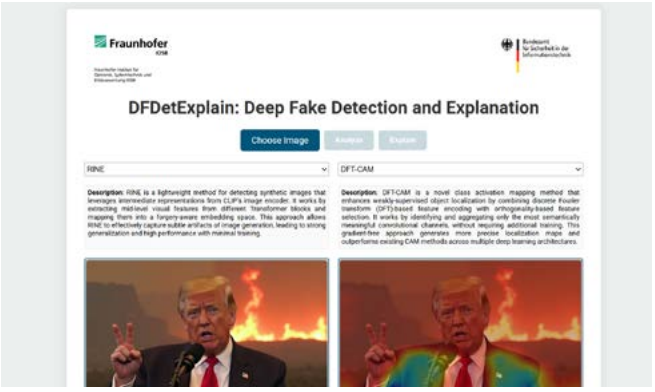


The traffic data we have collected in AVEAS can for example be used in simulations on the OCTAS® platform.



Web interface of the DFDet-Explain application developed in RealOrRender: Deepfake Detection and Explanation.

Detecting critical traffic scenarios for use in simulations: the AVEAS project

Simulation will play a key role in the testing and validation of automated and autonomous driving functions in the future. However, simulations cannot reliably replace real-world test drives until they reflect the complexity of actual traffic situations as realistically as possible, especially in areas of risk.

This was the objective of the AVEAS project, which was led by UnderstandAI GmbH and Fraunhofer IOSB and realized in partnership with Porsche Engineering, dSPACE GmbH, PTV Group, Continental, Allianz Center for Technology, GOTECH GmbH, Spiegel Institut GmbH, Karlsruhe Institute of Technology (KIT) and two other Fraunhofer institutes, EMI and IVI. Together with a number of national and international associates, the consortium developed scalable methods facilitating the targeted collection of data on critical real-world traffic scenarios and their transfer to models for scenario generation and simulation. This encompasses the privacy-compliant collection of traffic data in public spaces using infrastructural cameras, test vehicles and aerial imagery, the development of a unified data format (standardized in DIN SAE SPEC 91518: STRADE in conjunction with ASAM OpenLABEL®) and the generation of highly realistic end-to-end simulations from these data, covering everything from traffic scenarios and driver behavior to dynamics and sensor models.

The project results are available on the AVEAS project website in the form of extensive open-access publications, open-data datasets and open-source tools. They are intended to serve as the starting point for future developments in data-driven simulation for high-risk AI systems.

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RealOrRender: transparent detection of deepfake images

With their ability to create deceptively realistic images, generative AI models offer a wide range of possibilities, e.g. for creative applications or medical imaging. However, the associated risks are increasingly coming under scrutiny, particularly when these artificial images are deliberately used for disinformation. The aim of the RealOrRender project is to develop processes with which AI-generated images can be reliably and robustly distinguished from real photos.

RealOrRender takes a hybrid approach: A conventional classification process based on deep learning is combined with a method that evaluates how well an image can be reconstructed using a generative model. If the reconstruction deviates significantly from the original image, this indicates that the image is real. Combining these two approaches significantly increases detection accuracy, while ensuring that the system remains reliable even as generative models evolve and produce increasingly realistic results.

One of the project's key concerns is transparency: Rather than simply classifying an image as "AI-generated," the system should explain why it arrived at this decision. This is achieved by deploying various attribution-based and segment-based explainable AI processes to visualize the image features on which the decision is based. Evaluations performed using a large, purpose-built imaging dataset have shown that this explanation-oriented approach clearly outperforms many processes currently used in research. RealOrRender effective protection against image manipulation and establishes a robust foundation for the responsible use of generative AI content.

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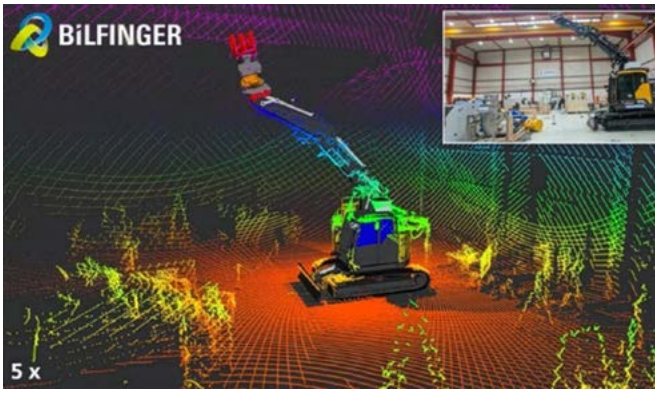
The LLM facilitates interaction with machines and process knowledge via text and speech.

LLM4OPC—communicating with industrial machinery in natural language

LLM4OPC facilitates interaction with industrial systems using a secure natural-language interface. OPC UA and Asset Administration Shells (AAS) connected through the Model Context Protocol (MCP) enable large language models (LLMs) to read live machine data, provide comprehensible explanations of system states, and execute actions—subject to human approval. The agent-based workflow design clearly separates the user interface, process logic and tools: A planner defines verifiable steps, a tool agent performs read/write operations and method calls, and a replanner ensures that state changes can only be effected with human input, confirming results by generating follow-up queries.

The result: Staff gain an auditable language interface for querying system states, navigating AAS information and securely initiating system functions. Standardized toolkits for OPC UA and AAS combined with LLM-ready modeling guidelines (consistent namespaces, qualified BrowseNames) facilitate reuse and scalability from edge to data center.

As of today, we can provide MCP toolkits for OPC UA and AAS with reference workflows and review mechanisms as well as secure reference architectures that guarantee observability and auditability when using language models to drive interaction with digital systems. One area to be developed further is on-premises operation with specialized small language models, which will bring AI expertise and data sovereignty directly to the production site.



AI-assisted teleoperation instead of directly controlling individual joints: experimental system with its digital twin.

Teleoperated retrieval system for the Asse II mine

Together with Bilfinger, we are developing a teleoperated retrieval system for recovering radioactive waste from the Asse II mine, commissioned by the Bundesgesellschaft für Endlagerung (Federal Company for Radioactive Waste Disposal, BGE). The project addresses one of the country's most demanding safety challenges: retrieving about 126,000 drums stored hundreds of meters underground in a corrosive, saline environment—some neatly stacked, others piled up or covered by salt.

Bilfinger is building a highly automated multifunctional excavator equipped with specialized tools such as custom grippers, milling heads and buckets. We contribute key robotics and AI expertise developed within the ROBDEKON competence center (cf. p. 13), including sensor fusion, 3D environment perception and machine automation. An inverse kinematics module lets operators position the tool intuitively while the machine coordinates the motion autonomously. Repetitive steps, such as placing retrieved drums into transport containers, will be automated in later stages.

A digital twin of the retrieval system mirrors the real environment, enabling analysis and optimization of operating states and movements before deployment. Operators control the process from a safe distance, supported by precise spatial awareness and assistance functions. The aim of our work is to increase staff safety, reduce cognitive workload in the control room and develop resilient, transferable AI solutions for robotic systems operating in extreme environments.

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We offer solutions for:

- Flexible production and value chains
- Resource and process optimization in production
- Digital twins for Industry 4.0
- Industrial communication and cyber security
- Industrial data ecosystems

Automation and Digitalization

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- KIS
- MIT
- MRD
- SPR

Customized IT for networked production ecosystems

The Automation and Digitalization business unit provides a highly focused range of services including 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: Industry 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 SmartFactoryOWL in Lemgo and the Karlsruher Forschungsfabrik (Karlsruhe Research Factory), we offer cutting edge development and demonstration environments for SMEs and for major corporations.

iosb.fraunhofer.de/ad

Circularity only scales when product and process data can be shared across companies«

How data foundations enable real world impact for circularity and sustainability in industrial production.

Mr. Pethig, Circularity has become a top priority in manufacturing. What's fundamentally changing right now?
At Fraunhofer IOSB we see a shift from voluntary initiatives to an operational requirement. Companies must increasingly report carbon footprints, material origins and compliance across the lifecycle. The bottleneck is fragmented data: if information stays locked in disconnected systems across suppliers, machine builders and factory operators, sustainability remains a reporting task, not a controllable performance lever.

If data fragmentation is the bottleneck, what does it take to make production circular and sustainable?
Two things must come together: sovereign data exchange and standardized information models. Data spaces such as Factory-X aim to enable interoperable, rule based data sharing between factory equipment suppliers and their customers, and they also address use cases like circular economy and energy consumption/load management. On top of that, digital twins and digital product passports must be machine-readable and standards-based. That is why we develop the FA³ST ecosystem: an open, modular tool landscape to create, validate, host and share Asset Administration Shells efficiently, including within trusted data spaces. Our open-source AASPortal integrates asset data from distributed systems and offers context-specific views—for example, to display digital product passports.

How does this connect sustainability with resilience, both in supply chains and on the shopfloor?
Circular strategies require options: alternative suppliers, routes and processing paths, evaluated against time, cost, quality and sustainability criteria. Open architectures like the ones we realized in the Smart Factory Web or in Catena-X and Factory-X show how supply chains can become more resilient while integrating sustainability constraints.

And inside the factory, automation makes the biggest difference when energy, resources and quality are controlled together in real time. In Smart-E-Factory, for example, we combine AI with modern factory energy concepts and use digital twins to create transparency in energy management—so improvements become measurable and repeatable.

What will decide whether these approaches reach broad adoption, especially among SMEs?
Lowering entry barriers. Companies need practical pathways to understand standards, test them with real assets and integrate them safely. That is why we complement R&D with enablement—through Transfer-X and hands-on data space workshops in our research factory environments, for example—so SMEs can move from concepts to implementation without betting everything on a one-off pilot.

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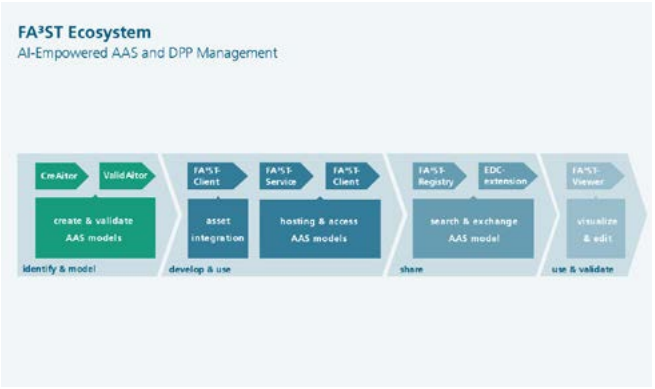
Data spaces are opening up new approaches to optimization and control for a flexible and interconnected energy system.



From creation to use and sharing: The FA³ST Ecosystem supports the full lifecycle of digital twins in Industry 4.0.

energy data-X: data spaces for a connected energy system

energy data-X is a core project in the Manufacturing-X ecosystem that is transferring the concept of sovereign data spaces to the energy sector. Its objective is to enable interoperable and secure data exchange between energy system stakeholders, thereby unlocking potential for new data-driven applications. Fraunhofer IOSB is contributing its expertise in data spaces, IT security and the energy sector while playing a key role in the technical implementation of core components.

One major focus of our work is the supply and further development of data space connectors based on the Eclipse Dataspace Connector. We provide key services such as a connector registry, a federated catalog and concepts for decentralized onboarding beside linking the connectors with the European Business Wallet. We also document the interoperability of these components for market roles in the energy sector, thus facilitating the practical integration of existing backend systems into the data space.

Additionally, we develop data-driven services within the data space. For the "FleX" use case, we are using optimization services to analyze and control energy systems on the basis of distributed information, for example from home energy management systems. This demonstrates how sovereign data spaces create tangible added value for a flexible, efficient and resilience energy system while forging vital links with industrial data space ecosystems such as Factory-X.

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FA³ST Ecosystem: Enabling AAS-compliant digital twins more efficiently and easily

Small and medium-sized enterprises (SMEs) are increasingly recognizing the potential of digital twins to improve production, maintenance and asset management. However, the task of creating and operating digital twins remains challenging, as it often requires the integration of heterogeneous systems and an understanding of complex standards such as the Asset Administration Shell (AAS), a widely adopted standard for representing interoperable industrial digital twins in Industry 4.0 environments.

Fraunhofer IOSB is developing the FA³ST ecosystem to address this challenge. It provides an integrated set of tools supporting the entire lifecycle of digital twins, including automated creation from existing engineering data, intelligent validation for AAS compliance and semi-automatic connection to physical assets and other data sources. The ecosystem also supports the automated deployment of digital twins as interoperable services, the visualization of asset information and the sharing of digital twins in data spaces. By combining these capabilities in a modular toolchain, FA³ST simplifies the development and operation of interoperable digital twins.

By abstracting technical complexity, the FA³ST ecosystem allows SMEs to create and use digital twins without requiring in-depth knowledge of the AAS or communication protocols. This significantly lowers adoption barriers while enabling SMEs to leverage digital twins and participate in secure and interoperable industrial data ecosystems.

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An open data ecosystem links supply chains with the shop floor: Factory-X lays the foundations for networked production.

Factory-X: Sovereign data exchange for mechanical and plant engineering

Factory-X is a key beacon project that forms part of the Manufacturing-X initiative and addresses digital transformation in mechanical and plant engineering. Its objective is to establish an open, collaborative data ecosystem that enables sovereign, interoperable data exchange between factory equipment suppliers and their customers. Fraunhofer IOSB is contributing its long-standing expertise in Industry 4.0 architectures, digital twins and secure data spaces, thus making a significant contribution to the practical implementation of data sovereignty in industrial value creation.

The core of Factory-X is a unified data space with basic services. Building on this foundation, eleven use cases have been specified in pre-competitive collaboration and are being implemented and validated as prototype business applications. We are contributing to the development of basic services for the digital twin based on the Asset Administration Shell (AAS) besides being involved in the use cases Manufacturing-as-a-Service—On Demand Manufacturing, Circular Economy, Energy Consumption and Load Management, Modular Production and Condition Monitoring-led Services.

One distinctive feature of Factory-X is the integration of horizontal data flows along the supply chain with vertical data exchange as far as the shop floor. This means that production data can now be used across company boundaries in compliance with the relevant standards for the first time. Our work is helping to translate existing Industry 4.0 concepts into scalable data space solutions and establish the foundations for resilient, future-ready production networks.

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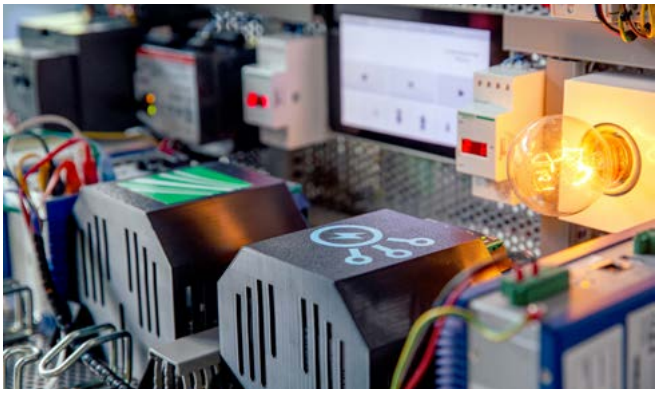

Mobile training demonstrator used by the Cybersecurity Training Lab for the energy and water supply sectors.

Cybersecurity Training Labs: Qualification in regulated fields of practice

Fraunhofer IOSB's Cybersecurity Training Labs are key components of our continuing education portfolio. We use learning environments specific to the production, energy and water supply sectors to train specialists and managers in the secure operation of networked systems. New regulatory requirements—particularly NIS 2 and the Cyber Resilience Act—are currently driving a significant increase in demand for sound, practice-oriented training.

At the Cybersecurity Training Lab for production in Karlsruhe and Lemgo, mechanical and plant engineers in particular receive assistance with the implementation of "security by design." Real automation components, industrial communication protocols and typical attack scenarios convey a profound understanding of threats and countermeasures. A successful training partnership with the VDMA Academy and Fraunhofer IEM along with numerous in-house training measures testify to the applicability of our approach in industrial practice.

The Cybersecurity Training Lab for the energy and water supply sectors in Ilmenau and Görlitz is intended for operators of critical infrastructure. This lab models supply networks in realistic environments, allowing cyberattacks on operational technology to be experienced and analyzed in practice. We have also established a new focus on game-like training formats: "Hack the Grid" allows participants to test attack and defense strategies in specific scenarios, thereby strengthening their technical understanding and ability to make decisions in realistic conditions.

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

Expertise in analysis and evaluation, contract research and technological innovation—from the physics of signal generation to the use of the information it contains

The Defense and Security business unit conducts research in the following fields: laser technology, 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 the 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, however, our work is embedded, wherever possible, in the research carried out for civil security and other applications. Networking with various committees, institutions and organizations within the EU, NATO and the scientific community plays an important role.

Our technologies and solutions are put to practical use by the Bundeswehr and others. Examples include ABUL (automated image and video exploitation for unmanned aircraft), CSD (Coalition Shared Data), DigLT (digital map table software), THS® (target handoff system) and semantic video analysis for security applications.

iosb.fraunhofer.de/vg

When you take a laser outdoors, the atmosphere becomes part of the system«

Directed energy in defense: why atmosphere, tracking and beam control matter as much as kilowatts—and how Fraunhofer IOSB tackles it.

Prof. Eichhorn, high-energy lasers have suddenly become central to defense technology debates. Why now?
Two trends are converging: major progress in fiber lasers and beam combining, and a rapidly changing conflict landscape with growing use of unmanned aerial vehicles. This makes directed energy attractive because it enables highly precise engagement at the speed of light while drawing only electrical power—an almost unlimited "magazine"—at a very low cost per shot. This is exactly the profile needed for accurate, repeatable counter-UAS measures.

Many people assume it's mainly about achieving "more kilowatts." Is that true?
High output power matters, but operational capability is defined by predictable irradiance on target. In practice, this means holding a small spot on a fast, dynamic object long enough to create an effect. That requires an end to end system view: sensors, optics, control loops and real time algorithms—plus the mitigation of atmospheric effects such as turbulence, absorption, thermal blooming and platform jitter. The laser is only one element in a tightly coupled chain.

Which core building blocks are you working on along this chain?
We cover the full span: scaling and characterizing laser sources, including beam combining; precise multi stage tracking concepts and sensors; and the simulation and modeling of atmospheric propagation so that performance can be predicted rather than guessed. In parallel, we investigate laser–matter interaction and laser safety, because field use demands both effectiveness and controlled risk.

How do you bridge the gap between models, lab setups and reality?
Validation is key. That's why we are setting up HELIKS, a flexible, container based mobile high energy laser investigation system. Its modular architecture enables experiments even where infrastructure is limited and supports high power beams via coherent coupling, allowing realistic measurements of safety, atmospheric propagation, laser–matter interaction and overall system performance. These data feed directly back into our full system simulations.

How do you make the leap from demo to dependable capability?
High energy lasers are not a single breakthrough component but a system of systems. Laser source, beam control, tracking, atmosphere and safety all interact. Dependable capability comes from investing in the less visible parts—robust tracking, propagation understanding and field experimentation—that turn impressive demos into predictable performance.

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High-energy lasers: HELIKS as a mobile research platform for directed energy systems

High-energy lasers (HEL) are emerging as a key technology for future defense and security applications, particularly in scenarios that require precise, scalable and cost-effective countermeasures. At Fraunhofer IOSB, we are addressing this field with a comprehensive, system-level research approach that spans laser sources, beam control, atmospheric propagation, target interaction and laser safety. One central element of this strategy is the development of HELIKS, a mobile high-energy laser investigation system designed to accelerate experimental research under realistic conditions.

HELIKS is conceived as a transportable, container-based experimental platform with modular architecture. It integrates the high-energy laser source, power supply, cooling, control and safety infrastructure into a self-sufficient system that can be deployed independently of local facilities. This design enables experimental campaigns in a wide range of environments and supports flexible system configurations tailored to specific research questions. With coherent beam combining of more than 90 laser channels and a total output power exceeding 100 kW, HELIKS provides capabilities that are currently unmatched in Germany and allow us to investigate performance regimes relevant to next-generation laser effectors.

The platform serves as a testbed for end-to-end investigations of directed energy systems. We use HELIKS to study laser beam propagation through the atmosphere, including turbulence, thermal blooming and scattering effects, and to validate advanced simulation models with real-world measurement data. In parallel, HELIKS enables the development and evaluation of high-precision target-tracking chains, adaptive optics concepts and beam control strategies required to maintain sufficient irradiance on fast-moving targets. The system also supports controlled experiments on laser-matter interaction, providing insights into material response, damage mechanisms and effectiveness under realistic engagement conditions.

A further key research focus enabled by HELIKS is laser safety. Directed energy systems introduce specific hazards related to direct irradiation, atmospheric scattering and reflections from targets or surrounding surfaces. By combining experimental measurements with detailed modeling, we develop methods for hazard assessment and risk analysis that are essential for the safe operation of high-energy lasers in open environments. The mobile and self-contained nature of HELIKS allows these investigations to be carried out under conditions that closely resemble operational scenarios.

With HELIKS, we are establishing a unique experimental infrastructure that links fundamental laser physics with applied system research. The platform is strengthening our ability to assess the maturity, limitations and operational implications of high-energy laser technology and providing a robust foundation for future research projects, technology transfer and cooperation with partners in defense and security.

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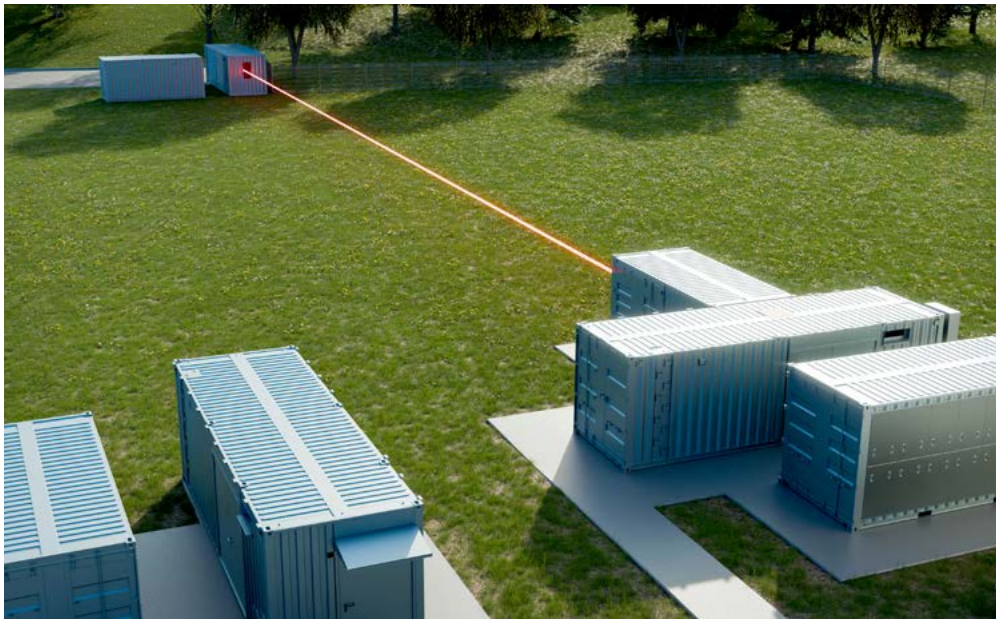
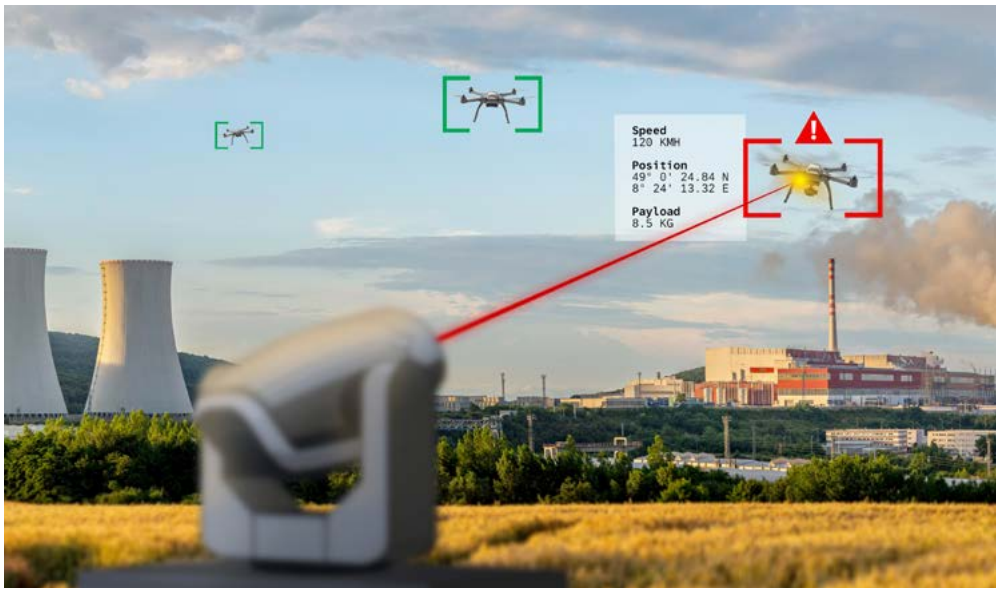


Mobile container test setup of the high energy laser system HELIKS.



Our vision of an integrated system that—like MODEAS—identifies and classifies drones and helps assess their threat potential while being capable of neutralizing them if necessary.

Detecting, classifying, tracking and combating small drones

In view of the growing threat posed by drones in both military and civilian settings, Fraunhofer IOSB has consolidated its research and development work on drone detection and countermeasures and formed a cross-departmental task force operating at multiple locations. This task force serves as a central hub where development pathways, contacts with potential partners and users, project launches and communications on this topic are brought together, structured and prioritized.

We focus on systematically identifying requirements from a wide range of operational scenarios, aligning them with our existing capabilities and using the results to develop robust concepts for technical solutions. This involves both analytical work and the creation and ongoing development of specific demonstration and reference systems. At the same time, we coordinate external inquiries and are aligning our roadmap as closely as possible with the plans for the innovation center for drones and drone defense to be established by the Fraunhofer institutes in Karlsruhe in collaboration with Karlsruhe Institute of Technology as part of Baden-Württemberg's Innovation Campus for Security and Defense.

Strategically, our goal is to ensure that our own system remains at the cutting edge of technology and, building on this, to develop specific sub-areas in accordance with our scientific strengths. These include detection and classification with optronic sensors (cameras in the visual and infrared spectrum), robust tracking and, as the next development step, the demonstration of countermeasures using high-energy lasers at wave-lengths optimized for eye safety, for example at 2 µm.

Depending on the use case, we can supplement this chain with specialized sensors such as high-speed and event-based cameras, gated viewing systems or laser Doppler vibrometers as well as other modalities such as RF scanners, acoustics, radar or lidar. These can improve detection reliability, range and classification accuracy.

The basis for our work is the research and demonstration system MODEAS (Modular Drone Detection and Assistance System) developed in earlier, internally funded projects. MODEAS uses radar for early warning purposes, combining it with optical sensors and laser range-finding for precise tracking. The video exploitation algorithms we use for detection, tracking and classification are designed to reliably identify and evaluate drones even against complex backgrounds such as vegetation or urban structures. The additional classification of drone type, size and possible payload facilitates the performance of a thorough situational and threat evaluation.

MODEAS relies on comparatively simple sensors that can be expanded by adding modules. In the long term, this approach offers the potential for significantly reduced system costs compared to many currently available solutions. This will expand the scope of application, for example for operators of critical infrastructure. The video-based recording and documentation of unauthorized drone flyovers has already been implemented. Based on the tracking quality achieved, our next step is to press ahead with the demonstration of effective countermeasures.

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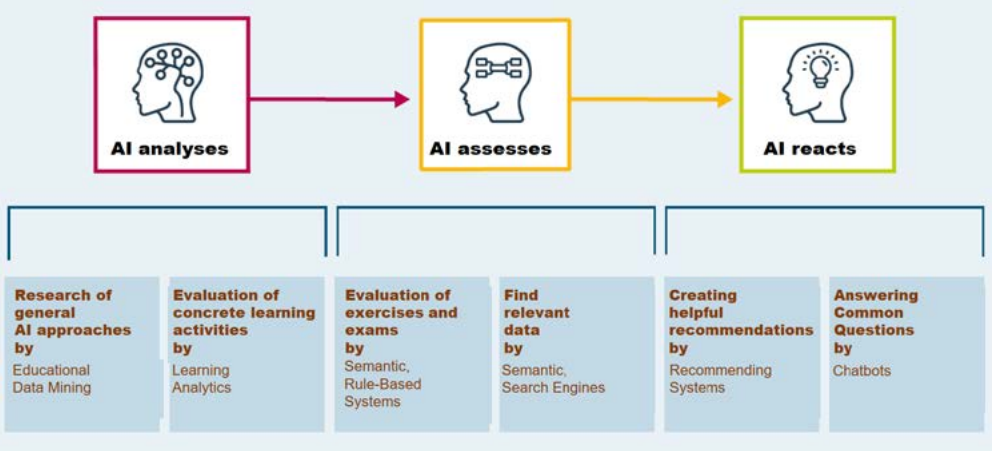


The application of AI to e-learning typically comprises (1) the capture and analysis of observable data, (2) the assessment of this data to produce insights on the learner's progress, and finally (3), a reaction such as the provision of recommendations or the initiation of a chatbot interaction.

Use of artificial intelligence for learning management systems

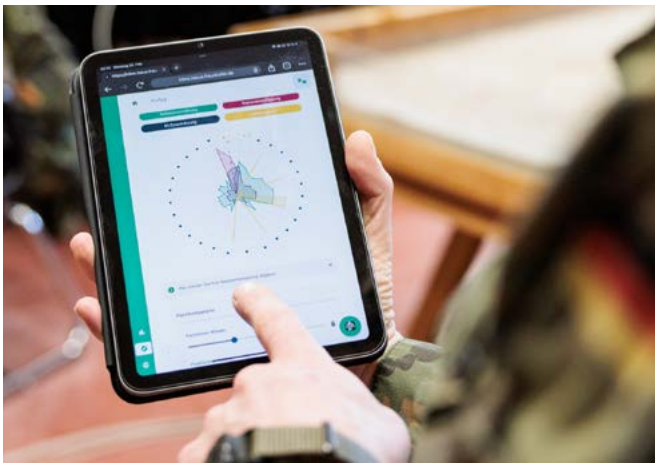
During the course of two consecutive studies commissioned by the German Armed Forces (Bundeswehr), we explored how artificial intelligence (AI) can enhance digital training environments and support a modern, efficient learning experience for military training. The project was a joint effort with the Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE and the Fraunhofer Institute for Open Communication Systems FOKUS and is considered a flagship project within the Bundeswehr training domain.

While the initial exploratory phase assessed the general potential of AI in military learning management systems (LMS), the follow-up study "KI LMS 2" concentrated on advancing these concepts into an extended demonstrator deployable within protected IT environments. In this study, requirements related to data protection, IT security and usability were systematically analyzed to ensure that the resulting solution meets the specific constraints of military training contexts. Additionally, a modular system architecture was designed to support personalized learning recommendations and adaptive learning environments.

Within the study, several AI-based functionalities were further refined, implemented in the demonstrator and assessed, emphasizing improvements in usability. The integrated AI components include a recommendation system, a learning analytics dashboard, personalized learning experiences with adaptive training tasks, semantic search and a competency analysis application. One particular highlight, considered the most attractive component by many users, is an AI chatbot allowing rapid access to regulations, course materials and learning information—an especially valuable capability in highly structured training settings.

The demonstrator was tested over a trial period at a German NCO School (Unteroffizierschule des Heeres), where its performance and practical value were evaluated. Study participants confirmed the added value of AI-supported features, particularly in scenarios requiring the efficient navigation of large learning materials and quick information retrieval.

Despite the technical and organizational challenges of classified IT environments, the project successfully demonstrated how modern AI technologies can optimize training and learning processes in the German Armed Forces. The results of the study, which was successfully completed at the end of 2025, provide a robust foundation to further operationalize AI-supported education in protected IT environments.



The KI-LMS 2 study examines the use of artificial intelligence (AI) for education and individual training in the German Armed Forces.

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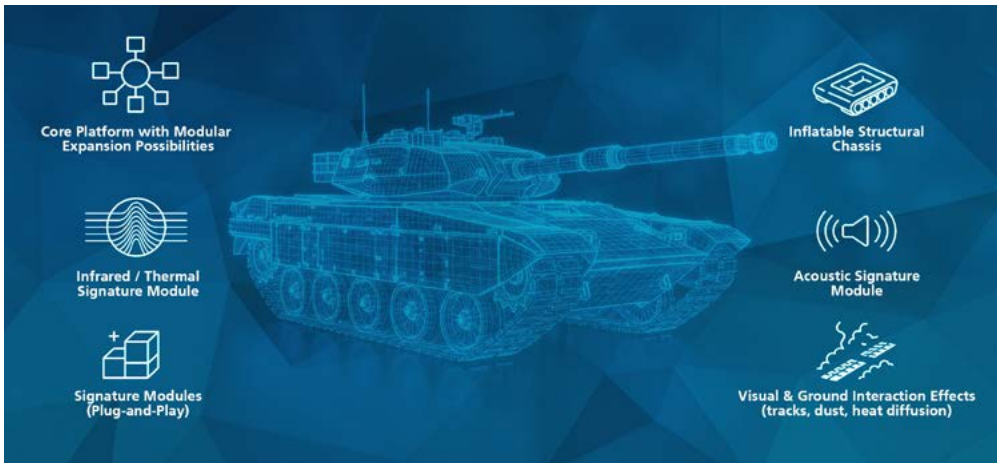


Multilevel evaluation of camouflaged objects with Fraunhofer IOSB software.

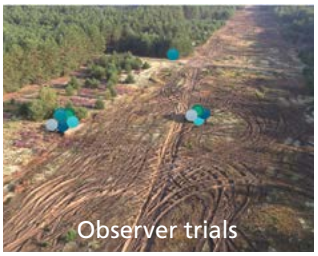
Multispectral decoy systems for modern warfare

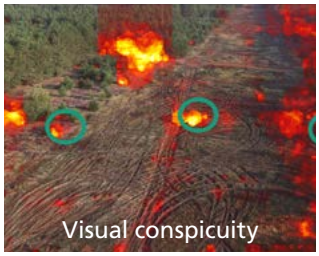
Over many years of research, Fraunhofer IOSB has built extensive expertise in the evaluation of camouflage materials and military decoys, including systems such as StandCam (Standard Decoy for Camouflage Materials), inflatable systems and mock-ups made of wood and fiberglass. Each of these approaches offers distinct advantages in terms of deployment speed, cost-effectiveness and signature fidelity. Comprehensive field trials form the basis for assessing deception effectiveness across operational scenarios and climate conditions. Drawing on this experience, we developed the ALOPEX tool (ALgorithms for cOnspicuity Parameter EXtraction) to enable the quantitative and objective evaluation and optimization of signatures across relevant spectral bands.

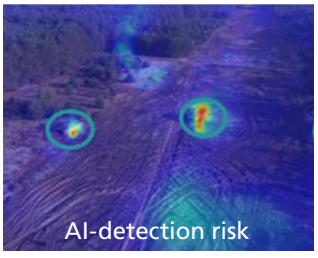
The relevance of camouflage and deception has increased markedly in the light of recent conflicts, in which enemy forces frequently engage decoys compelling adversaries to expend valuable resources on false targets. Passive decoys, such as system replicas of high-value assets, have successfully deceived optical aerial reconnaissance systems, evidencing the continued viability of this approach even against sophisticated surveillance platforms. These real-world validations underscore the strategic value of investing in advanced deception capabilities.

Looking forward, increasing reconnaissance capabilities and the widespread use of drones and satellites will demand more advanced multispectral decoy systems that address multiple detection modalities simultaneously. Modern decoys must therefore be capable of covering multiple dimensions of deception to remain effective. Beyond realistic signature replication across the electro-optical, electromagnetic, acoustic and radar spectra, physical "signs of life" such as credible vehicle track imprints and observable activity indicators, including simulated position changes and operational patterns, are essential for decoy credibility. Without these elements, even spectrally accurate decoys may be dismissed by trained analysts or sophisticated algorithms that look for contextual clues of genuine military activity.

Moreover, the combined threat posed by human analysts and AI-based reconnaissance systems must be systematically analyzed and addressed. Artificial neural networks are increasingly being used for military reconnaissance because they can rapidly process large volumes of imagery and sensor data. However, they can be deceived in ways that are fundamentally different to those applicable to human observers. While conventional camouflage and decoys focus on visual deception for humans, AI-targeted concealment may require abstract, highly adaptable patterns specifically designed to exploit AI vulnerabilities and classification weaknesses. Effective modern decoys therefore require a dual evaluation approach that measures deception effectiveness against both human observers and AI systems, since the features that make a decoy realistic for one are not necessarily effective against the other.







Outputs from our CARPET, ALOPEX, and ALOPEX AI tools show how current camouflage performs—insights we use to design improved multispectral patterns, measures, and decoys.

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We offer solutions for:

- resilient systems for energy and water management, transformation planning
- crisis and disaster management, cultural heritage protection
- environmental and water information systems
- IoT monitoring solutions for municipalities and cities
- safe food and sustainable agriculture, processing and sorting systems

Energy, Material Cycles and Crisis Management

Contact

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Departments involved

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

From sensor data to intelligent services

Whether measurements, sensor data or other heterogeneous data sources: The Energy, Material Cycles and Crisis Management business unit assists with the consolidation and utilization of complex data for decision support, optimization and operational management systems. We bring together a wealth of expertise in sensor networks, data management and data-driven methods such as analysis, modeling, simulation and forecasting.

Our services range from basic research, technology consulting and contract research for industry to the design and implementation of entire systems. Our solutions are used in a variety of areas, including energy management, water supply planning, environmental information, crisis management, and the automatic sorting of bulk goods for food and recycling processes.

Our software technology includes FROST® (an implementation of the SensorThings API), the PERMA®cloud environment for analysis and modeling algorithms, and the cloud-based platform EMS-EDM PROPHET® for energy services, forecasting and optimization methods. We also use WaterFrame® information systems for water quality management and UVC LED disinfection solutions. The Electronic Situation Dashboard for Civil Protection (ELD-BS), which we are continually developing further, has been supporting command staff operations and crisis response in Baden-Württemberg for many years and can be flexibly adapted for other practical applications.

iosb.fraunhofer.de/emc

Resilience requires not only better technologies, but new ways to bring them into use«

How Fraunhofer IOSB combines Earth observation (EO), technical guidance and pre-commercial procurement to bring climate resilience solutions into practice—and why this matters beyond crisis management

Dr. Moßgraber, what is changing fundamentally in climate-related crisis management?
We are seeing a shift from reacting to events towards anticipating them earlier and more systematically. Short-term warnings remain important, but resilience against floods, droughts, wildfires or cascading infrastructure impacts increasingly depends on understanding longer-term developments such as soil moisture, vegetation stress and water availability. The EU project PCP WISE addresses this predisaster phase by translating EO data into operationally relevant products for climate resilience.

Why does this also change how innovation has to be organised?
Because these emerging requirements are often not covered by existing market solutions. In PCP WISE, the state-of-the-art analysis showed that available tools address only part of the operational needs, but do not form integrated, interoperable systems ready for cross-border use. In precommercial procurement, instead of buying products, public buyers launch a competitive process to commission R&D services, including design, prototyping and testing of alternative approaches.

How does this work in practice?
Within PCP WISE, a Europe-wide tender invites multiple suppliers to develop prototypes in successive competitive phases. After each phase, solutions are evaluated against joint operational and technical criteria, and only the most promising approaches move forward. This allows end users to compare alternatives early, influence development based on real needs and reduce the risk of later integration problems. It creates transparency for public authorities and a realistic path from prototype to near operational use for innovators.

What role does Fraunhofer IOSB play in this process?
We support the translation of operational requirements into technical guidance that underpins the procurement. In PCP WISE, this includes co-designing use cases with users, structuring requirements, and defining principles for interoperability, compliance to standards and operational robustness. EO data, such as Copernicus products, are an important input, but the focus is on making technologies deployable within real systems.

Why is this relevant beyond crisis management?
Similar challenges arise wherever public actors need digital or data driven capabilities that are not yet available on the market. PCP provides a way to align technology development with real demand and to shorten the path from innovation to application. In PCP WISE, this logic is applied to climate resilience—but the underlying approach is transferable far beyond this domain.

More information

www.iosb.fraunhofer.de/pcp-wise

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OpenCitySense brings structure to urban sensor networks, thus building trust and improving efficiency.

OpenCitySense—intelligent sensor management for smart cities

Modern cities maintain extensive sensor networks to monitor air quality, transportation, water and energy. The data collected are then used for controlling and planning purposes. However, new challenges are emerging as the systems grow in number and diversity: malfunctions are not being detected in time, outages are going unnoticed, data quality is becoming difficult to assess, and maintenance costs are rising. Dissimilarities between manufacturers, transmission types and data formats are making central administration more difficult and operations more complex.

OpenCitySense is a software solution that enables municipal sensor networks to be managed on the basis of open standards. The application visualizes the status of all sensors in a location-specific manner, continuously monitors data quality, and identifies anomalies such as depleted batteries, contamination or damage. The FROST server and the OGC SensorThings API facilitate the integration of new sensors, the adjustment of configurations and the central management of heterogeneous systems. A unified data model maps the entire life cycle from initial set-up to uninstallation.

This results in transparent sensor networks with verifiable data quality. Municipalities and utility providers can plan their maintenance activities more efficiently, shorten response times and cut operating costs. The solution is manufacturer-independent, scalable, and can be integrated into various smart city applications.

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Measurement campaign for the multi-sensor collection of data from lightweight packaging waste at Fraunhofer IOSB.

K3I-Cycling—challenges in plastics sorting

In the AI Application Hub Plastic Packaging, AI methods are used all along the value chain to make plastic packaging more sustainable. The specific aim of the joint research project K3I-Cycling is to increase recirculation and promote the use of recyclates as secondary raw materials. As its contribution, Fraunhofer IOSB is researching sorting processes based on optic sensors that cover the spectral range from visible light to mid-infrared. Another key focus is material characterization with AI models and the creation of a multi-sensor dataset for benchmarking AI models.

In an extensive measurement campaign conducted in July 2024, around 500 kg of lightweight household packaging waste was recorded on a conveyor belt in order to generate a multi-sensor dataset. Six complementary sensors were used: a color camera, an NIR hyperspectral camera, radar, a laser-based height sensor, an X-ray measuring device and a thermography camera. Temporal synchronization was achieved by a central trigger unit, while special markers facilitated the spatial registration of the sensor data. The annotation of the approximately 2400 images is nearing completion, and the first part of the resulting benchmark dataset has already been published.

AI models for analyzing lightweight packaging waste were developed in parallel and the results used to create the PacK3Ing Analyzer demonstrator. This sensor-based system enables lightweight packaging waste to be precisely characterized in real time by fusing color and hyperspectral data with deep learning. Material analysis is an important part of a functional circular economy and facilitates the production of high-quality recyclates as secondary raw materials during the material recycling process.

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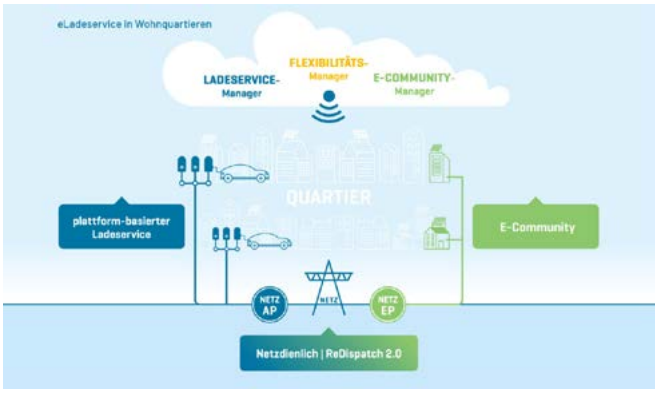
PrognoSF aims to accurately predict local flash floods by exploiting all available data sources with AI-based algorithms.



Charging service in residential neighborhoods: schematic diagram of the concept behind Shared AC.

PrognoSF is making cities resilient to cloudbursts

As climate change and urban densification raise flood risks, our solution delivers hyperlocal, minute-by-minute forecasts and longer lead times so that responders act earlier and impact is reduced. In PrognoSF, developed in a multi-year internally funded project, we are fusing high-resolution DWD (Deutscher Wetterdienst) precipitation forecasts with real-time sensors for rainfall, water levels and land use, sourced from remote sensing and SmartCity platforms. At the core is an open data and AI stack: our open-source OGC SensorThings API implementation (FROST® Server), PERMA® to orchestrate Docker-based AI modules and WebGenesis® for intuitive decision support.

Data from LoRaWAN-enabled sensor stations, local rainfall nowcasts, automated satellite-driven land-use analysis, and water-level and discharge models that blend historical records, live telemetry and weather provide improved situational awareness. Open standards ensure seamless integration, scalability and interoperability.

The project has been completed and validated in first use-cases with authorities and first responders in hands-on workshops that demonstrated high potential for sharper risk maps, longer reaction windows and transparent, explainable alert chains.

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Shared AC project: platform-based charging service for electric vehicles in residential neighborhoods

Providing a cost-efficient charging service for electric vehicles is particularly challenging in residential neighborhoods due to the limited parking space, high cost sensitivity among residents and long vehicle charging times. We and our partners addressed this issue in the "Shared Area Charging" (Shared AC) project, for which we developed a system approach that combines the revenue advantages of a shared charging infrastructure with the cost benefits of automated service platforms and the billing advantages of locally marketed solar energy within energy communities.

The aim of the project was to create a platform-based system solution for charging services in residential settings. The charging service is based on the shared area charging principle: Having multiple charging points per location makes it possible to supply entire neighborhoods that have more users than charging points, i.e. a participant ratio greater than one. Electricity costs are reduced by using technical solutions that facilitate the use of locally generated energy from energy communities, and by integrating charging processes into the neighborhood's energy supply in a manner that serves the grid.

The system solution developed during the project forms the basis of a charging service that can be scaled up nationwide. It combines an innovative business model with several charging points at each charging location (multi-charging point), dynamic electricity tariffs for vehicle charging and the use of local photovoltaic systems with simultaneous grid-serving integration.

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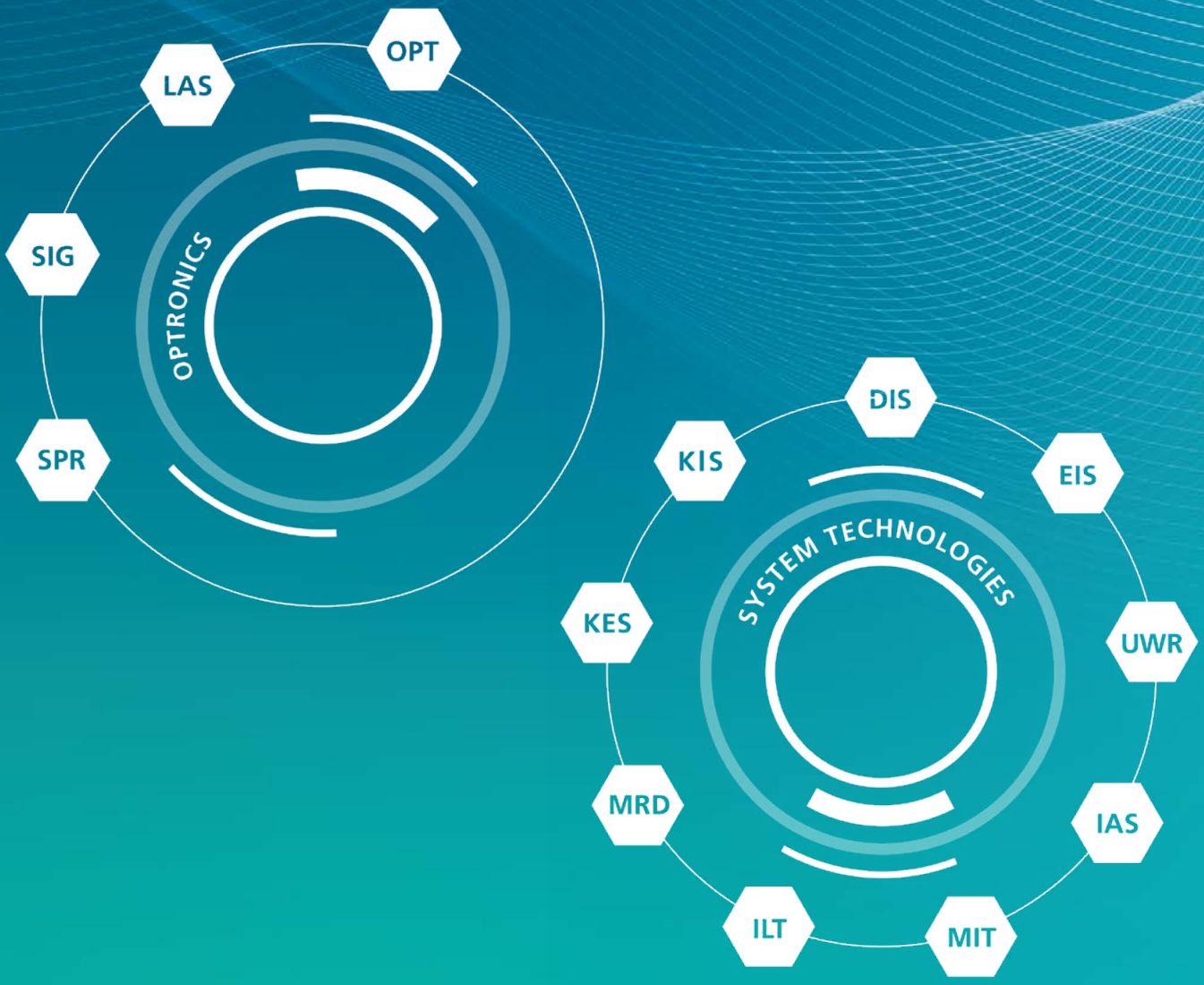
Departments

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. We focus on the special requirements of optronic and defense applications.

Head of department

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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

We develop high-power continuous wave and pulsed solid-state and fiber lasers, non-linear converters and related components for the near-, short-, mid- and long-wavelength infrared range (NIR, SWIR, MWIR, LWIR) to meet the demands of optronic applications. We model complex laser dynamics and resonator performance both analytically and numerically for solid-state and fiber lasers as well as non-linear converters. Our goal is to enhance beam quality and wavelength coverage in high-average power and high-pulse-energy sources, and to develop new or optimized components. Our crystal growth and active fiber fabrication activities focus on enhancing active laser and non-linear optical (NLO) materials and components for optimum performance.

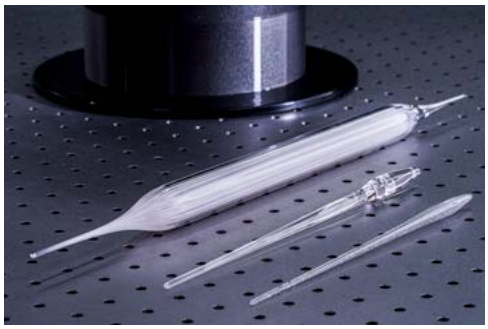
Applications, products and services

Our laser sources can be used in applications such as communication, illumination, metrology, medical laser surgery and defense. They can be optimized for pumping non-linear converters, yielding high-pulse energy and average-power sources at other wavelengths. We make our innovations—from single components like crystals or fibers to full laser systems—available to the Bundeswehr (German Armed Forces), industry or research partners. Internally, 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 components according to R-on-1 or S-on-1 (ISO standard) protocols. Laser damage (LIDT) 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 the facilities and equipment necessary for modern laser research in the NIR to LWIR range. These include a variety of high-power pump sources (diodes and fiber lasers) in the NIR and SWIR range, a large selection of active laser materials such as crystals and fibers, and 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 a number of very rare electro-optic metrology devices and equipment for manufacturing specific crystals, fiber-optic and optical components.

High-precision opto-mechanical components are realized in collaboration with our central workshop to guarantee the utmost precision and robustness needed at all stages from research to fieldable laser systems.



Left: Various oxide laser crystals with different active dopants (rare-earth elements and transition metals).

Right: Micro-structured fiber preform and drawn fibers – an example of critical components for record-breaking results at LAS.

Spotlight activities

Crystal growth for laser crystals
The laser technology department is significantly increasing its capabilities with regard to crystal growth and the machining of laser crystals. The two growth furnaces available in 2025 will be increased to nine by the end of 2026, allowing us to deepen technological sovereignty and security of supply for rare-earth-doped laser crystals, for which larger size, lower impurity levels, higher damage thresholds or higher yield are important. Another important factor is the elaboration of components from grown single crystals, including cutting and polishing. New capacities are therefore being created for the machining and polishing of various hard-brittle materials to provide high-optical-quality laser elements and optical crystals. In all, an additional 350 m² of lab surface for the growth, processing and analytics of laser crystals will be realized by the beginning of 2027.

Record values from pulsed fiber lasers
Our team has set several new world records in pulsed fiber lasers in the 2 µm wavelength range. In quasi-cw thulium fiber lasers, we broke the previous record of 1.1 kW of output power with a novel value of >1.2 kW using an all-fiber design. We accomplished this by developing new in-house fiber pump combiners that outperform commercial products in both transmission and pumping efficiency, enabling power levels well beyond 3 kW.

We have also set new records in fiber amplifiers. Using multi-stage fiber master-oscillator power-amplifier (MOPA) architectures, we realized around 210 W of average power at 2.1 mJ pulse energy and 50-ns-square-shaped temporal pulses. When we used these amplifiers to pump a non-linear ZGP-based converter, we set another record: a conversion efficiency of over 69% from the pump to the MWIR signal and idler waves.

New clean-room labs and lab environment
Two new clean-room labs and a pre-clean-room infrastructure allowing for reducing contamination and easier access between the labs have been realized. They also include a new aeration system for better air control and contamination reduction. One new lab wing is dedicated to SWIR high-energy-lasers (HEL) including cutting-edge equipment for high-power fiber component manufacturing and metrology, areas for testing and optimizing new concepts, and a laser demonstrator lab with over 10 kW of pump power and facilities for performing 2 µm HEL interaction testing at various distances.

The second new lab is dedicated to solid-state laser and non-linear converter systems including the latest state-of-the-art equipment for evaluation and metrology in the SWIR to LWIR. It will also offer new capabilities for testing and analyzing the interaction of lasers and optronic systems.

New labs: LAS increased its lab space with additional laser labs for research in the near- to-long-wave infrared field.

OPT | Optronics

The Optronics department develops and optimizes optronic systems and measuring technologies, using both experiments and theoretical models to evaluate their performance.

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. Using our laboratory evaluation systems and prototypes of novel sensing methods, we experiment with active and passive optronic sensors and sensor systems to assess their performance and evaluate possible applications. We develop prototypes for new imaging paradigms such as quantum ghost imaging and compressed sensing. Moreover, we conduct research into high-energy lasers (HEL) using simulations and experiments. The department also uses analytical and computational approaches to model sensors and imaging processes, which includes 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 investigate how laser sources could threaten optronic systems.

Applications and products

Our TRM4 software can calculate the performance of scanning and staring thermal imagers and cameras for visible to SWIR wavelengths. TRM4 is continually adapted to changing technology and applications.

Our OSIS simulation tool simulates sensor images for user-defined imaging systems and scenes. Convolutional neural networks (CNN) are used to evaluate the simulated images. Safety requirements for (high-energy) lasers represent a unique challenge. To estimate HEL's hazard ranges, the reflectance of all objects in the field must be known, including that of 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 using 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 the capacity to capture images through a harsh atmosphere such as smoke.

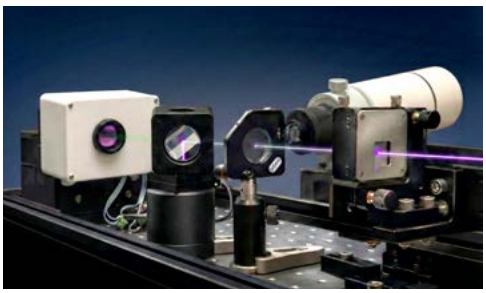
Infrastructure and lab facilities

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 have also developed a mobile high-energy laser

research system with coherent coupling, called HELIKS (cf. page 50), to conduct experiments in various setups and environments.

Spotlight activities

Quantum Ghost Imaging



Laboratory setup for Quantum Ghost Imaging.

In the Optronics department, an advanced quantum ghost imaging (QGI) setup for remote sensing has been developed to enable active illumination that is practically impossible to detect. Operating at extremely low irradiance in a broadband range around 1.5 µm, it emits statistically distributed entangled photons that are indistinguishable from ambient noise, facilitating the first practical implementation of covert active imaging and ranging.

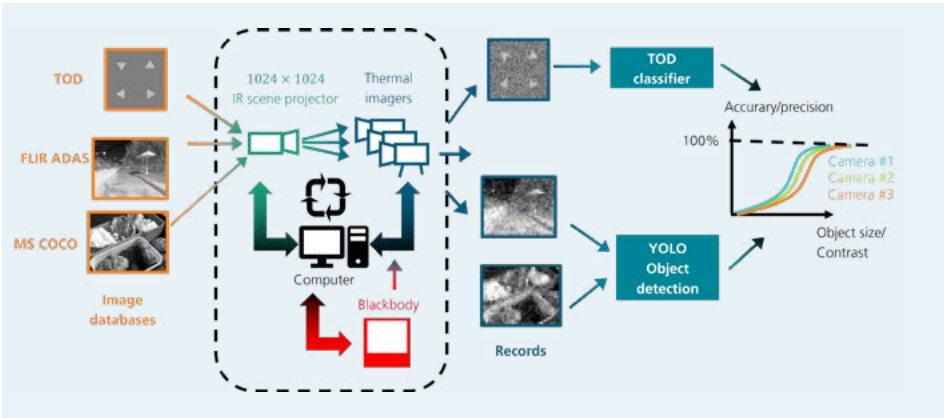
This is achieved by the system's very high photon efficiency, which suppresses background noise through coincidence detection of entangled photon pairs. Noise and signal are separated at the single-photon level using exclusive information from a secure quantum key obtained from the entangled partners of the illuminating light photons. As no moving components are required, the architecture offers high reliability and strong potential for miniaturization into a compact device; the central technical challenge lies solely in precise time-stamping and coincidence electronics. Use cases include covert active imaging and ranging in environments where fully concealed operation provides clear benefits for safe, discreet and efficient performance.

Image-based assessment using an infrared scene projector

We have developed a laboratory measurement setup with integrated measuring software that facilitates automated, reproducible assessments of the performance of thermal imaging devices. The setup focuses on thermal imaging devices used in combination with AI algorithms for object and target detection. The core component is a high-resolution infrared scene projector with a resolution of 1024 x 1024 pixels and a frame rate of up to 400 images per second. Both the projector and the test equipment are controlled centrally, allowing test sequences of real and artificial scenes to be generated and projected onto different devices before taking synchronized camera measurements. Non-uniformity corrections and temperature calibration can be effected with feedback from a black body. Projecting annotated image databases from remote sensing, driver assistance and surveillance applications onto various thermal imaging devices enables us to evaluate the performance of object detection models for the corresponding images.

Top: Laboratory setup for the image-based assessment of thermal imaging devices.

Bottom: Workflow for assessing the performance of thermal imaging devices with respect to AI algorithms for classification and object detection.



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.

Head of department

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Research groups

- Warning Sensor Systems
- Optics of the Atmosphere
- Signature Management
- Signature Assessment
- Adaptive Optics
- Quantum Superresolution

iosb.fraunhofer.de/SIG

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 modeling and correction of atmospheric and underwater turbulence. We are involved in the HELIKS testbed (cf. page 50) for the investigation and correction of environmental influences on high energy laser propagation—a cloud chamber for laser propagation studies is under development. We also operate a robot-driven setup to automatically measure bidirectional reflectance distribution functions (BRDF). Our environmental simulation facility enables the controlled reproduction of solar radiation, sky coverage and crosswind conditions for signature assessment. Finally, extensive environmental forecasts and simulations involving effects such as turbulence, transmission and scattering allow us to make a well-founded assessment of electro-optic propagation.

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

Artistic illustration of image reconstruction through spatial mode demultiplexing.

and Matisse, electro-optical/infrared scenario simulation programs such as TAItherm, ShipIR/NTCS and Cameosim, and multi-physics environments such as Comsol and Ansys.

Spotlight activity

Quantum superresolution

Light can travel in many distinct patterns, known as optical modes. These modes are a powerful way to describe how light behaves and how it can be measured. When many modes are involved and the quantum nature of light becomes important, we enter the field of multimode quantum optics. This framework allows us to understand subtle properties of quantum light, such as entanglement, and—crucially—how to design measurements that extract the maximum possible information from light. These ideas are particularly important for imaging.

The Quantum Superresolution group, recently established within the Signatorics department, applies multimode quantum optics to develop new imaging techniques that overcome the traditional resolution limits imposed by diffraction. Our main experimental approach is spatial mode demultiplexing (SpaDe). Instead of recording light with conventional camera pixels, SpaDe separates incoming light into carefully chosen spatial modes, each carrying specific information about the object being imaged. By measuring these modes directly, we can resolve features smaller than the diffraction limit in a fully passive way, while making optimal use of every detected photon.

This efficiency is especially valuable when working with light-sensitive samples, such as in biomedical imaging, or in situations where very few photons are available, such as astronomical observations or remote sensing.

Our research combines hardware and software development. On the hardware side, we build reconfigurable optical devices that perform spatial mode demultiplexing using linear optics. On the software side, we apply tools from quantum information theory to develop data-analysis algorithms that optimally extract information from these measurements, enabling precise discrimination and characterization of objects well below the diffraction limit.

Together, these efforts bridge the gap between fundamental quantum optics and practical imaging technologies. By turning SpaDe-based superresolution into a robust and deployable tool, our work helps bring quantum-enhanced imaging methods into real-world applications ranging from advanced microscopy to space and astronomical observations.

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 reflective materials.

Head of department

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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 to characterize and inspect 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, 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 are increasingly utilizing hyperspectral imaging in smart agriculture and along the food chain.

Infrastructure and lab facilities

Our department operates an image exploitation center and a cross-application multi-sensor lab to realize a machine vision system that is capable of performing a given task and to determine how accurate and resource-intensive the solution will be. 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.

Spotlight activities

AI-supported quality inspection with hyperspectral imaging
The quality of fruit and vegetables is largely assessed by manual visual inspection, which is subjective, labor-intensive and limited to surface defects. Crucial quality parameters such as internal bruising, sugar content or ripeness often remain undetected, resulting in fluctuating product quality, inefficient sorting and avoidable food losses along the supply chain.

Our fruit scanner uses hyperspectral imaging to reveal the invisible quality parameters of entire crates.

To address this, we are developing an AI-supported inspection system that uses hyperspectral imaging (HSI) up to the near-infrared range for non-destructive analysis of fruit and vegetables in real time. The fruit scanner demonstrates how entire crates can be analyzed within seconds: Each item's spectral signature reveals both internal quality traits and visible parameters such as color and damage. AI-based image and data analysis converts these measurements into objective indicators of quality. As a research demonstrator, the system shows how spectral sensor technology can be integrated into machines, processing lines or mobile platforms to facilitate the automated classification and sorting of produce.

Identification of chemically treated wood for improved waste wood recycling

Germany generates 8–10 million tons of waste wood per year, only around a quarter of which is recycled, primarily for chipboard production. Increasing the recycling rate of wood is essential not only for sustainability reasons but also for economic benefits, besides being politically desirable. One challenge is that not all waste wood is recyclable, due to chemical contamination and the general impurity of the material.

We are therefore developing solutions that combine cameras with a sorting mechanism to facilitate the processing of the waste wood stream. Chemically treated wood presents a particular challenge, as it cannot be identified within the visual range of the optical spectrum. However, treated wood alters its spectral signature outside the visible range, which can be detected using hyperspectral short-wave infrared (SWIR) cameras. Suitable AI models can then classify the material accordingly and transmit the information to the sorting machines.

Waste wood is a valuable resource but still presents major challenges in recycling.

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.

Head of department

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Research groups

- Electrical Energy Systems
- Cross-sectoral Energy Systems
- Energy Informatics
- Cybersecurity for Energy and Water

iosb.fraunhofer.de/KES

Research areas and expertise

With our specific expertise in cognitive and integrated energy systems, energy informatics, AI-based decision support systems, system analysis and design, digital twins, data space technologies 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. One essential key to the success of the transformation is the digitalization of energy supply systems. This is where the KES department at Fraunhofer IOSB can make significant contributions by providing expertise and technical solutions. We also offer cybersecurity services for the energy and water supply sectors; such services are becoming increasingly important as the digitalization of energy and water supply systems progresses.

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 the 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 the efficient automated processing of a wide range of energy management and energy system processes, including forecasting energy demand, managing balancing groups, power plant scheduling, the optimal operation of sector-coupled energy systems, or market communication. The department also offers comprehensive solutions facilitating the transition of industry, commercial zones and residential districts into the new energy world. Furthermore, we offer successful training courses in energy data analysis and cybersecurity in partnership with the Fraunhofer Academy.

Infrastructure and lab facilities

The KES department maintains an extensive lab infrastructure at the Ilmenau site and the Görlitz branch lab, addressing essential aspects of the energy system's value chain. Demonstrators and laboratory setups, spanning the spectrum from energy technology to energy economics, are used to address research questions and develop service offerings for customers. The IT security lab serves as the core of the Cybersecurity Learning Lab "energy and water supply".

Spotlight activities

GridCompanion: Innovative AI agent solution assists operators with grid operation

The scope of tasks performed by system operators is becoming increasingly complex. They must collect and evaluate vast amounts of data in real-time and factor this information into operational decisions. With GridCompanion, Fraunhofer researchers are introducing an innovative AI agent designed to support operators in this demanding environment.

GridCompanion equips distribution system operators (DSOs) with powerful, locally deployable tools for intelligent grid analysis and decision support. At its core lies a chat-based assistant that allows operators to interact naturally with the system. In agent mode, it combines proven grid simulation tools with advanced data analytics to deliver structured, situation-specific insights. In knowledge mode, GridCompanion uses retrieval-augmented generation (RAG) to access and interpret internal documentation and domain knowledge, providing accurate and explainable answers to operator queries.

By intelligently connecting technical data, simulations and operational knowledge, GridCompanion accelerates decision-making, enhances situational awareness and builds trust in AI-assisted processes. The result: more efficient, transparent and resilient grid operation—ready for the challenges of tomorrow's energy systems.

Initial practical tests with GridCompanion are being conducted in the grid laboratory at Fraunhofer IOSB-AST.

Advanced data analysis improves medium-term forecasting of electrical grid load by 76 percent

Our energy experts have conducted a comprehensive data analysis of the electrical grid load for SWE Netz GmbH, Erfurt's local utility network operator. The amount of energy transported to end consumers via the power grids has been steadily declining since 2010—a phenomenon that can also be observed throughout Germany at the distribution and transmission grid level. The expansion of decentralized local generators such as photovoltaics is one of the reasons for this development.

KES researchers examined extensive load data available over a period of fourteen years and also used publicly available data from the market master data register. These two data sources made it possible to perform a much more accurate analysis and modeling for SWE Netz GmbH. A simulation based on 15-minute intervals for the reference year 2024 reduced the error in mapping the grid load from 3.89 GWh to 0.93 GWh, equivalent to the annual consumption of over 800 households or an improvement of 76 percent compared to the model currently in use. In addition to the enhanced mapping of daily and seasonal patterns, the increase in model accuracy was achieved primarily through the integration of long-term trends.

Better grid load forecasting helps minimize economic risks: inside the digital control center of SWE Netz GmbH Erfurt.

KIS | Cognitive Industrial Systems

The Cognitive Industrial Systems department develops intelligent components and processes for flexible, resource-efficient production. We focus on AI systems beyond the prototype stage, employing machine learning to analyze large datasets and large language models to enhance human-machine interaction.

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Research groups

- Intelligent Cyber-physical Systems

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Research areas and expertise

Our research concentrates on optimizing production processes by leveraging large datasets to enhance efficiency and productivity. We place a strong emphasis on AI engineering within systems engineering, integrating artificial intelligence into complex systems. Our expertise ranges from sensor instrumentation in production facilities to the implementation and deployment of AI-based software systems.

We leverage large language models (LLMs) in agentic systems to improve human-machine interaction, revolutionizing how users engage with production assets.

In close collaboration with our industrial partners, we develop advanced AI technologies and deploy them in long-term industrial environments, well beyond the prototype. Crucially, this collaboration lets us address real-world process environment requirements, including tool wear, varying raw material quality and changing environmental conditions.

Applications and products

In digital retrofitting, the key question is strategic: Can reliable information for process improvement be derived from existing machine data or added sensors, for quality predictions, predictive maintenance or efficiency analyses?

We offer the "AI Potential Pilot", a tool for the quick, systematic assessment of data potential in specific use cases, identifying opportunities and risks early to inform investment and technology decisions. A fully automated AI training pipeline performs statistical analysis of process variables and their dependencies, then develops machine-learning models enabling anomaly detection or process value prediction. The outcome is a detailed report comparing model performance, enabling rapid decisions on whether digital retrofitting and AI are beneficial for the specific equipment.

Our "Rapid Instrumentation and Control Environment (RICE)" is a toolkit for rapid data collection and active process exploration in industrial settings. RICE provides hardware tools for minimally invasive data collection while actively intervening in processes, e.g. automatically exploring parameter spaces and gathering data to train process-specific AI models. RICE has been prototypically established at the research factories in Karlsruhe and Lemgo. This provides real industrial infrastructure for validating AI methods under production-near conditions. One demonstration scenario uses an injection molding process, well-suited for machine learning due to its many measurable parameters, such as temperature profiles, mold filling and movement sequences.

Infrastructure and lab facilities

The KIS department is tightly connected to the Karlsruhe Research Factory, enabling

us to set up, operate and optimize industrial processes at scale with industrial partners. The Factory's on-site data center provides sufficient storage and computing capacity to run AI methods locally, thus supporting low-latency applications and keeping sensitive data on the premises.

Spotlight activities

Machine Learning for Textile Industry (ML4Tex)
Trützschler Card Clothing in Neubulach is the leading manufacturer of high-performance card clothings for cards and roller cards used in the international textile machinery industry. The process is highly complex, requiring <0.5 mm cutting precision at speeds of several meters per second.

The project Machine Learning for Textile Industry (ML4Tex) optimizes this process by predicting final product quality during production. It also targets the wider manufacturing cycle, discovering resource-efficient, environmentally friendly solutions through a data-driven approach.

This control center collects data from sensors on the production line at Trützschler

Data from sensors and raw materials along the line is combined with quality data from Trützschler's quality assessment department. Machine learning models relate production parameters to quality outcomes, and insights are shown on a shop-floor dashboard to enable immediate adjustments.

Furthermore, a high-resolution camera system is to be developed with a resolution <5 µm. This camera will be able to detect a huge number of wire defects online, an achievement that is not yet possible at this time.

The technical infrastructure is already established, essential data are being gathered, and the initial implementation has begun to deliver measurable added value to Trützschler, such as reduced scrap and earlier defect detection. This is generating interest in the next phases.

Helping industrial AI solutions succeed beyond the prototype stage
Many AI projects fail to move beyond the prototype stage due to technical complexity, weak cross-disciplinary collaboration, limited high-quality training data and the need for continual retraining as environments change and models drift. We address this using systematic approaches centered on the Process Model for AI Systems Engineering (PAISE®) and associated tools. This framework enables a comprehensive AI pipeline, from production line to applications suitable for long-term deployment. We have also published a white paper in cooperation with Fraunhofer IAO and IPA titled "AI beyond the prototype", and offer workshops on these AI Systems Engineering methods to help advance AI solutions beyond the prototype stage.

The process model PAISE® is the core of the methods that allow us to advance AI applications beyond the prototype stage.

DIS | Digital Infrastructure

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

Head of department

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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. In order to provide context-sensitive situation analyses, computer systems must be able to monitor the cyber-physical system using sensors and localization. We design smart sensor systems for machinery and equipment, work on real-time data processing, and construct software-controlled networks with 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. We deliver industrial cybersecurity expertise and solutions that empower organizations to securely design, operate and monitor connected production systems and achieve digital sovereignty. 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 these areas.

Infrastructure and lab facilities

We run two living labs in cooperation with the Machine Intelligence department and the University of Applied Sciences and Arts Ostwestfalen-Lippe (TH OWL). Both labs offer a full range of services designed to support a variety of customers on their digital transformation journey: SmartFactoryOWL, a living lab for industrial automation technologies, and Lemgo Digital, a Smart City living lab. At the Cybersecurity Training Lab, we offer courses in IT/OT security for production in partnership with the Fraunhofer Academy. These are tailored to the needs of small and medium-sized enterprises. The department also has specialized laboratories available to customers: 5G Application Center (www.5g-anwendungszentrum.de), TSN Test Laboratory (www.tsn-testlabor.de) and the world's first authorized omlox testing lab for indoor localization.

Spotlight activities

Industrial communication using Ethernet Time Sensitive Networking
The introduction of industrial communication based on Ethernet TSN requires high-per-

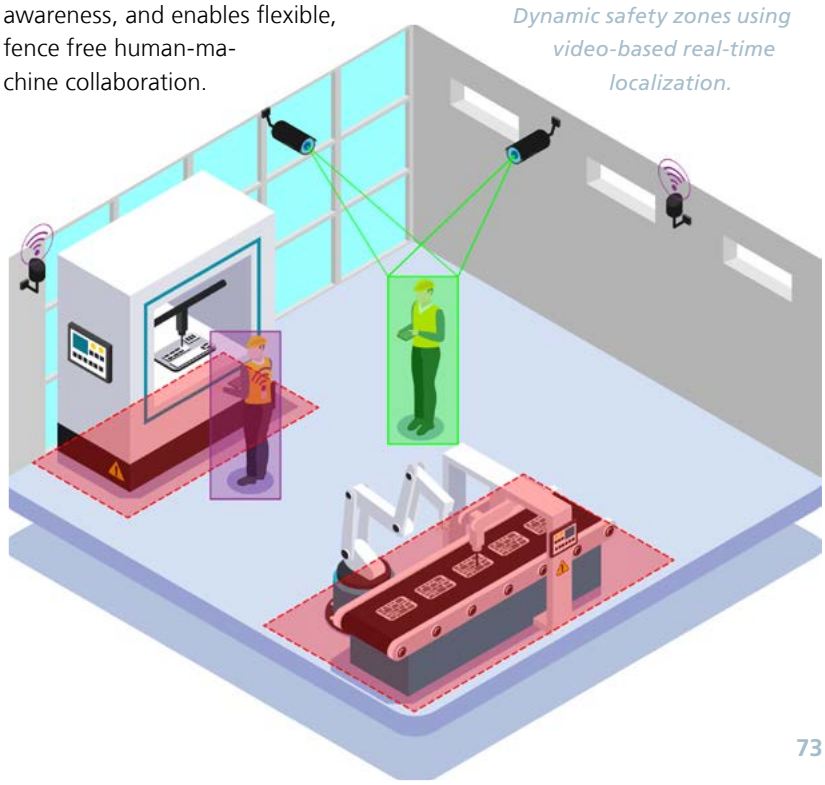
Development and testing of industrial communication systems.

formance embedded systems and network engineering solutions that facilitate the configuration, diagnosis and optimization of networks. The DIS department develops solutions for these challenges and has established the corresponding laboratory infrastructure. Practical implementation takes place in embedded systems, including hardware, field-programmable gate array (FPGA) and software development. One key aspect of the service portfolio is the testing of communication systems for real-time capability, robustness, interoperability and compliance with relevant standards. The TSN test lab established for this purpose contains high-quality test equipment. Research is also being conducted into AI-based network management methods that will make the configuration and diagnosis of TSN networks more manageable in the future.

Open interoperable real-time localization
omlox is the first open, vendor-independent locating standard for industrial applications. It harmonizes position data from heterogeneous technologies—UWB, BLE, RFID, GNSS and vision—into a unified global coordinate framework. With standardized models for devices, zones, fences and common APIs, omlox enables cross-vendor interoperability, real-time geofencing and event handling without bespoke integrations. This reduces vendor lock-in and total cost, enhances accuracy and resilience through multisensor fusion and redundancy, and speeds deployment. The results are scalable location services for asset tracking, worker protection, collision avoidance, and software-defined safety across the shop floor.

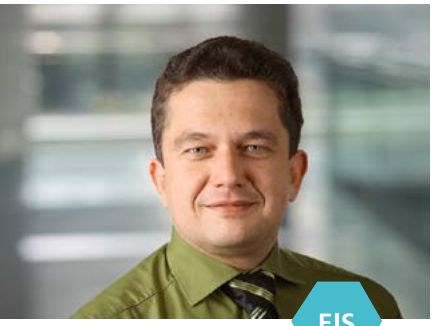
The SafeInLoc project applies omlox to create software defined safety in dynamic production. It fuses high precision localization with AI based vision, aligning detections in the same coordinate space via omlox certified middleware. Operators draw virtual safety zones on a map; when a person enters, the zone turns red and triggers alerts, or the machine stops in real-time. Multi technology tracking mitigates occlusion and interference, providing accurate, low latency protection without rigid fences. Demonstrated in a real world factory testbed, SafeInLoc advances interoperable safety, supports collision awareness, and enables flexible, fence free human-machine collaboration.

Dynamic safety zones using video-based real-time localization.



EIS | Embedded Intelligent Systems

The Embedded Intelligent Systems department conducts research and develops embedded real-time systems engineering solutions for a wide range of applications.



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Research groups

- Cognitive Autonomous Systems
- Smart UV-Systems

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Research areas and expertise

The Embedded Intelligent Systems department specializes in applied systems engineering. In mobile machine automation, we develop autonomous driving and control systems through R&D focused on modeling, simulation, hardware-in-the-loop testing and real-world validation. AI-based methods support localization, navigation, path planning and control. For UV systems, we create disinfection solutions (flowing media/surfaces) and photocatalytic processes using UVC LEDs to inactivate pathogens. Multiphysics simulations coupling radiation with fluid dynamics enable precise LED arrangement and dose calculation. Prototyping and small-series production are integral to our expertise.

Applications, products and services

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

Infrastructure and lab facilities

Our high-quality laboratories are fitted out 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.

Spotlight activities

Automation of vehicle attachments
The Cognitive Autonomous Systems (KAS) group at Fraunhofer IOSB-AST focuses its research on the automation of mobile work machines. Research scientists in the living lab develop technologies that enable machines to autonomously execute work processes ranging from precise path guidance and automated tool control to efficient human-machine interactions. The fields of application include municipal services, road maintenance, agriculture and industrial logistics. The objective is to enhance quality, efficiency and operational safety while reducing staff workloads.

One example is the automated cleaning of roadside delineator posts. Recurrent tasks of this kind are frequently performed by road maintenance services under significant time pressure and with considerable safety risks. Automation offers an ideal solution to these challenges.

Reduces employee workload and increases safety: automated delineator post cleaning.

Our approach is based on retrofittable vehicle attachments for existing municipal vehicles. We develop automated driving functions and attachment control using sensors and AI to facilitate accurate environment monitoring, object recognition and tool positioning. A digital twin of the machine system has been created for purposes of simulation, training and algorithm optimization. Validation under real operating conditions ensures reliable transfer into practical application. Municipal authorities benefit from improved roadside safety, reduced personnel expenses and the economically efficient modernization of existing vehicle fleets using retrofit solutions.

Photocatalytic air purification and disinfection

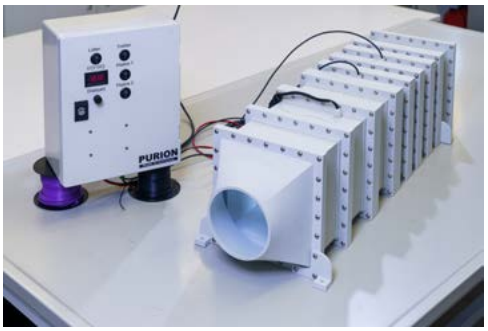
Antibiotic-resistant pathogens are a growing threat to humans and animals alike. Air quality plays a critical role in livestock housing, as many infections are transmitted via aerosols. But pathogens are not the only problem: Volatile organic compounds (VOCs) in animal excreta also pollute the air in the livestock housing, impair animal health, and have detrimental effects on the environment and buildings.

The EIS department and its partners have now developed a novel continuous air treatment system as part of the "DesGefUV" project funded by the **Federal Ministry of Agriculture, Food and Regional Identity** (BMLEH). This combines UVC LED-based disinfection with photocatalysis to reduce chemical pollutants, both in one scalable device. UVC radiation efficiently inactivates microorganisms while effectively activating photocatalytic processes.

Air quality, microbial load, and dust levels were investigated over the course of a two-year field test at a turkey breeding facility in Thuringia housing 4,000 animals. The results showed that dust particles impair the effectiveness of photocatalysis. This problem was solved by installing a multi-stage filtration system with a dual-stage cyclone and an air washer.

The humidified air also accelerates the formation of hydroxyl radicals, thus increasing the degradation rate of organic pollutants. Tests showed that the disinfection rates achieved by UVC LEDs are up to ten times higher than those achieved by conventional mercury lamps at the same radiation dose.

Furthermore, the technology could potentially improve indoor air quality in other settings ranging from food production facilities to hospitals.



Multi-stage photocatalytic reactor for ventilation systems.

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 digital twins, product passports, health, mobility, smart cities, environmental data and crisis management.

Head of department

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Research groups

- Modeling and Networked Systems
- Smart Factory Systems
- Architecture and Information Systems
- Industrial Cybersecurity
- 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 and International Data Spaces (IDS). 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 FROST®, 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, Bitkom, VDI/VDE, DIN/DKE, IEC, IIC and OGC.

Infrastructure and lab facilities

With the Smart Factory Web, an IIC testbed, we promote the concept of marketability solutions that use open standards for the visualization of production capacities and plants in manufacturing. We use various test centers to advance our research activities, including an Industry 4.0 model factory, an IoT test center, a safety test environment for automation and communication components (ISuTest) and an HLA-based certification test center for Distributed Simulation Federations. We also operate an IT security laboratory.

Spotlight activities

Security Testing Labor
Our security testing lab offers comprehensive facilities for testing the security of industrial automation and control systems. Our test system ISuTest facilitates automated black-box testing via an Ethernet interface to identify

ELD-BS is used by authorities all over Baden-Württemberg for crisis management purposes.

vulnerabilities in industrial communication protocols such as PROFINET or MODBUS/TCP. We support manufacturers by testing their components, providing access to our laboratory for their own tests, or helping them set up their own security testing labs. The aim is to identify vulnerabilities at an early stage and improve the resilience of networked production systems.

Electronic Situation Dashboard for Civil Protection (ELD-BS)—more than a staff information system

With the Electronic Situation Dashboard for Civil Protection, we are making a decisive contribution to crisis management in all regions of the state of Baden-Württemberg. As a staff information system, ELD-BS assists decision-makers with cross-agency communication, provides comprehensive overviews of situations and facilitates situation assessment by providing direct access to crisis-relevant information. ELD-BS is constantly being developed further, with new functions added in response to user feedback. The crisis object database, for example, not only supports the planning of large-scale emergency operations but also provides the necessary basis for public information on emergency meeting points. The central information system for disaster prevention vehicles and equipment not only assists administrative authorities with their daily work but also benefits fire brigades and aid organizations by simplifying their administrative tasks.

Making production more flexible and resilient with Manufacturing as a Service (MaaS)

MaaS is changing manufacturing, moving it away from rigid, vulnerable supply chains towards open, flexible, resilient production networks, with participants who find each other and coordinate their activities through MaaS marketplaces. The core idea is to match the specifications for a component with the manufacturers' capabilities. With this in mind, we created the Digital Sustainable Supply Chain (DiSC) ecosystem as a test field; this is a modular platform based on open standards that uses AI-supported logic and a microservice architecture to facilitate the matching process.

Our work focuses on developing architectures in near-production environments together with an open-source architecture toolkit for experimenting with federated digital ecosystems. We also test MaaS scenarios such as supply chain interruptions, heterogeneous data models and the semantic mapping of product specifications and production capabilities.

Our solution is based on the reference architecture Smart Factory Web, which we developed as a testbed for the Industry IoT Consortium (IIC). It was recognized at the Factory Innovation Awards 2024 (finalist in the category "Industry 4.0 in Practice").

Demonstration set-up for the Industrial Security Testing Framework ISuTest.

More information

www.isutest.com

www.iosb.fraunhofer.de/eld-bs

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.

Head of department

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Research groups

- Intelligent Systems of Systems
- System Architectures
- Networked Information Management

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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, thus facilitating 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 decision-making abilities they need. Our competences include designing, implementing, and evaluating system solutions for interactive data and information 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 in the deployment of groups of heterogeneous mobile sensor carriers and robots.

Applications and products

We develop components supporting the collection and analysis of heterogeneous data and information, components for interactive image exploitation and reporting, 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, including mission planning and management as well as evaluation and fusion of the sensor data and derived information,
- AIUSIT, a multi-layered AI framework enabling the use of unmanned systems in intelligent teams coordinating themselves to reach the tasked mission goals, particularly also within the context of Multi-Domain Operations (MDO),

SiUSpace aims at safe drone operations in U-space.

- a framework for supporting adaptivity in technology-based learning applications, enabling the applications to adapt to the learner, e.g., in terms of learning preferences or learning progress, and Findoo, a semantic search engine for finding relevant course contents for targeted learning.

Spotlight activities

FALCON (Fight Against Large-scale Corruption and Organized Crime Networks)
The three-year Horizon Europe research project FALCON addresses significant challenges faced in the global fight against corruption. A key concept in FALCON are the Corruption Intelligence Pictures (CIPs), which are intended to provide a holistic view of various areas of corruption.

When compiling the CIPs, the first step is to develop and validate objective corruption indicators. Next, powerful data analysis tools are designed and implemented. These software tools help update the CIPs, enabling a comprehensive assessment of corruption risks and the making of informed policy decisions. They also support the investigation and prosecution of individual cases.

FALCON benefits from our extensive experience in the fields of applied Artificial Intelligence (AI) and interoperable data spaces and architectures. We are responsible for the overall technical coordination, the development of the Common Representational Model (CRM) and the design of pilots in which the FALCON tools are tested and evaluated.

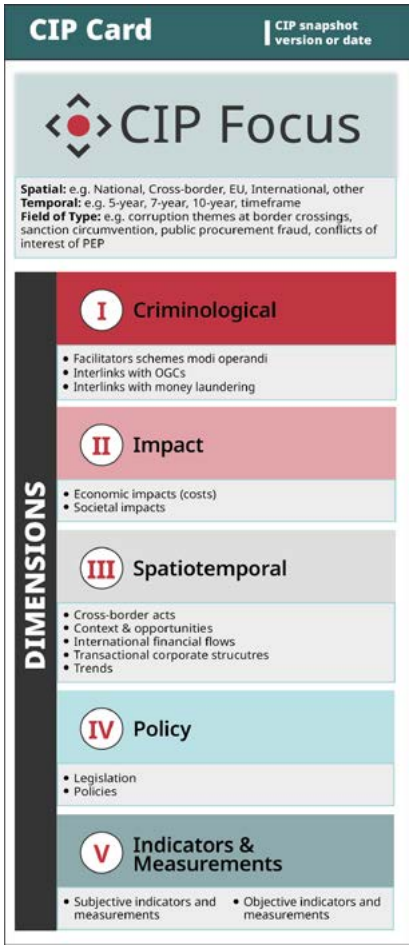
The ontology-based CRM enables joint exploitation of multiple data sources related to corruption, such as public tenders, news archives or cryptocurrency transactions, and facilitates information exchange between the different tools and with investigators of corruption cases.

SiUSpace (Safe Drone Operation in U-Space)
The collaborative project SiUSpace, funded by the German Federal Ministry of Transport, aims to make drone operations safer.

U-Spaces (areas in lower airspace designated for drone traffic) currently control only drones integrated into the framework. However, threats often originate from outside, e.g., from weather events, from incidents on the ground such as large fires, crowds, police operations, and from non-cooperative or defective flying drones and other flying objects. To effectively counter such threats, it is essential to identify and assess them in time to prepare and initiate appropriate measures if necessary.

SiUSpace integrates data from various external sources (such as drone detection systems, weather services, authorities and organizations with security responsibilities) to enhance the safety of drone operations and the surrounding environment in U-Space. We are also investigating how data on the technical status of drones (generated through monitoring and self-diagnostics) can be collected and used to further improve safety and security. Using AI, potential threats are identified and assessed, and actionable recommendations for stakeholders are generated. We also contribute innovative methods facilitating the planning of safe flight paths and evasive maneuvers for different types of drones.

FALCON Corruption Intelligence Picture (CIP) Card.



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.

Head of department

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Research groups

- Machine Learning
- Big Data Platforms
- Assistance Systems
- Mathematical 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 and AAS. Thanks to machine learning, we can predict how real processes will behave, ensure system integrity and diagnose the operating status of plant machinery. We use mathematical programming to optimize production planning and control. 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 and interaction design. Business management expertise complements our technological perspective, enabling data-based value creation.

Applications, products and services

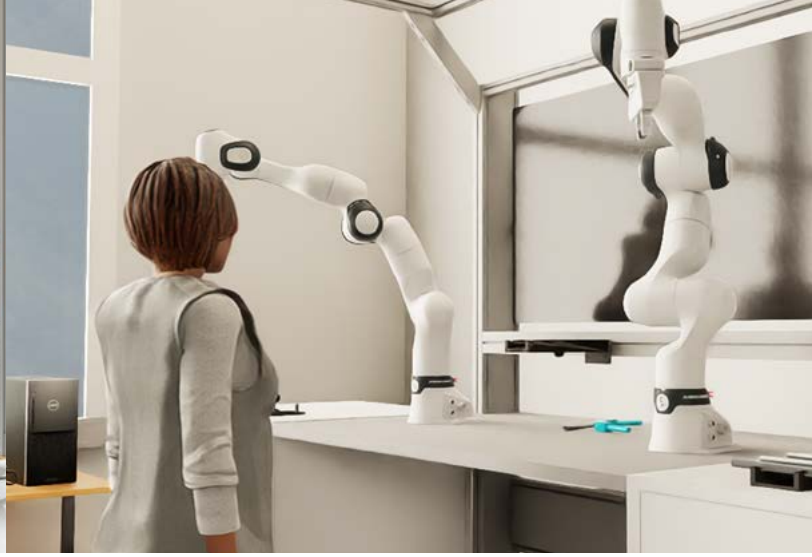
The range of possible applications and markets for our products is virtually endless. From modern, networked production in the automotive industry to small workshops, from robot cells to handheld drills—we can gather sensor data in all kinds of environments and use it in simulation models in order to streamline processes and generate useful knowledge. Our vision: human-centered, adaptive and sustainable automation based on reliable, explainable artificial intelligence and open standards.

Infrastructure and lab facilities

SmartFactoryOWL, a joint initiative of Fraunhofer IOSB-INA and TH-OWL in Lemgo, 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 facilitate analysis of the potential of AI, identifying suitable use cases, applying AI algorithms and networking systems with one another. In this way, we help companies use data profitably in the long term and strengthen the innovative, trustworthy and secure exchange of data in the industry.

Spotlight activities

Data and AI for sustainable engineering (GoProZero)
GoProZero, a project of the "it's OWL competence network", is developing solutions for circular and resource-efficient products. GoProZero delivers practical methods and digital tools—powered by AI and Digital Twins—that help extend lifecycles, close material



EXPLORE is reducing the gaps between real and virtual worlds.

loops and accelerate the transformation to a zero-emission circular economy. In GoProZero, MIT focuses on the standardized provision of reliable emission factors and upstream product carbon footprints for interoperable Digital Product Passports and lifecycle data management. As part of a lighthouse project with connection technology manufacturer Weidmüller, MIT is developing robotics for automated disassembly in a refurbishment application scenario. In another lighthouse project with CLAAS, we are developing a framework for standardized, semantically enriched (meta) data sets and ML models, thus supporting refurbishing strategies for harvesters.

Hybrid Experience Platform for Human-Centered Automation (EXPLORE)
The EXPLORE project aims to establish a research infrastructure for the development and optimization of high-fidelity Digital Twins for human-centered automation solutions. In cooperation with the University of Bielefeld, a platform leveraging massively parallel GPU processing together with intelligent automation technologies from SmartFactoryOWL is reducing the gap between simulations and physical environments. The platform also makes it possible to virtually test and optimize machines and plants according to changing requirements and conditions. Additionally, EXPLORE enables the application of AI based robotics in SMEs by providing high-quality synthetic data for training purposes. The project is being funded by the North Rhine-Westphalian Ministry of Economic Affairs, Industry, Climate Protection and Energy and co-funded by the European Union.

A strong consortium: representatives of the 14 partners in the "it's OWL" GoProZero project at the presentation of the funding decision by Mona Neubaur, North Rhine-Westphalia's minister of economic affairs.

MRD | Systems for Measurement, Control and Diagnosis

The department of Measurement, Control and Diagnosis analyzes, models and optimizes technical processes in manufacturing, energy and water infrastructures, robotics and mobility applications.

Head of department

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Research groups

- Process Control and Data Analysis
- Automotive and Simulation
- Autonomous Robotic Systems

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Research areas and expertise

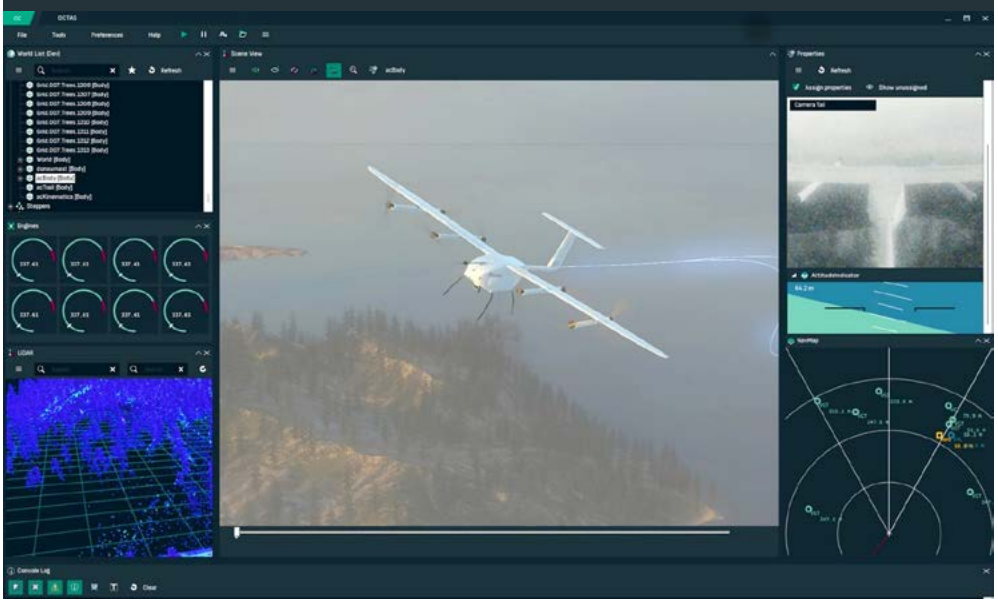
Our modeling, simulation and data analysis capabilities range from analytical, knowledge-based and data-driven methods to the modeling, simulation, synthesis and fusion of sensor systems. They include cutting-edge technologies in the fields of artificial intelligence (AI) and deep learning, such as large language models, generative AI and transformers, classical analytic methods, such as block-oriented and finite element models, and machine learning for classification, condition monitoring, causality analysis and environmental sensing. We develop autonomy algorithms for mobile robots—including construction machines—in unstructured environments along with simulation platforms for autonomous vehicles and mobility systems. Our expertise in real-time signal processing covers 3D data generation and analysis, visual navigation and content-based image retrieval and evaluation. In short: We make critical autonomous systems operate safely, robustly and efficiently.

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 dynamic field of mobility systems, our mission is the development of safe, robust and sustainable AI. This includes the open OCTAS® simulation platform, the generation of synthetic datasets and AI-based perception methods for automated and autonomous mobility. Applications range from automated road, rail and air transport to sustainable intermodal mobility solutions and privacy-safe mobility data processing. In robotics, we develop complete autonomy stacks including algorithms for localization and mapping, interactive path and trajectory planning, safe operation, and control of complex robotic kinematics. Applications range from service and inspection, logistics, security, precision farming, waste disposal and decontamination to missions in hazardous environments.

Infrastructure and lab facilities

We operate a large test site for autonomous mobile robots, which includes an outdoor area and a dedicated indoor lab. Here, we test how autonomous systems perceive their environment and plan motion in complex, unstructured spaces. Two VERTEX test vehicles are available and approved for autonomous operation, thus facilitating the development and validation of automated driving functions. As a partner of "Test Area Autonomous Driving Baden-Württemberg (TAF-BW)", we contribute expertise in privacy-safe traffic data collection and safety testing.



OCTAS® enables the modular and seamless simulation of any aspect of autonomous systems, including dynamics, sensors, communications and hardware interfaces.

Spotlight activity

OCTAS®: an open, modular simulation for autonomous systems and AI

OCTAS® (www.octas.org), which we developed in cooperation with various partners within Fraunhofer and in the fields of academia, research and industry, is an open, modular framework for the simulation of autonomous mobility systems, robotics and AI. Its platform-independent, plugin-based architecture enables unprecedented scalability with regard to new use cases and domains: from automated road vehicles and robotics to unmanned aerial vehicles, from hardware-in-the-loop testing to synthetic data generation for training and testing AI and deep learning models.

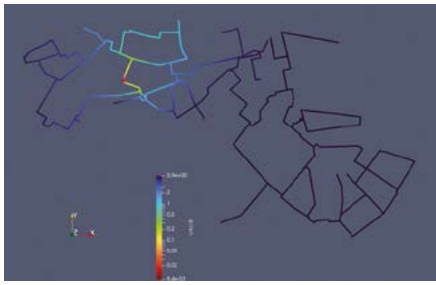
Its ability to expand almost any simulation functionality through easily exchangeable, standards-based plugins enables anyone to contribute models, functions or interfaces and distribute these under a license of their choice, from open to commercial. Existing models range from ground and aerial vehicle kinematics and dynamics through LiDAR and camera sensors to traffic flow, procedural environment generation, generative AI and a wide range of interfaces, for example CAN, ROS1, ROS2, Mavlink and tools such as Blender.

3SmartFW: detecting leaks in district heating networks

The "3SmartFW" system aims to enhance resource efficiency and supply security in district heating networks. By enabling the early detection and localization of leaks, it helps conserve water and energy while reducing the risk of pipe bursts and consequential damage. In the event of an incident, automated valves at key network points ensure minimal service disruption and maintain system pressure.

Autonomous heavy machinery

Autonomous heavy machines are transforming the future of the construction industry. Our research focuses on enabling robust autonomy in unstructured and hazardous environments. Projects like the autonomous excavator ALICE demonstrate how intelligent systems can perform complex tasks such as excavation and object handling without human intervention. Leveraging multimodal foundation models, we develop scalable AI architectures that combine perception, planning and interaction—paving the way toward adaptive, cooperative fleets of autonomous construction machines.



Localization of a leak in a district heating network (red area) through combined analysis of pressure measurement data and online network simulations.

Autonomous robotic systems from Fraunhofer IOSB.

UWR | Underwater Robotics

The Underwater Robotics department conducts research into 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.

Head of department

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Research groups

- Underwater Vehicles

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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 real-time 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 into warning systems for flash floods and improving the resilience of water supply systems.

Our main office is located in Ilmenau, but the department also has a location in Rostock.

Applications, products and services

We develop control algorithms for underwater vehicles and underwater robots for the purpose of exploring, inspecting and manipulating underwater infrastructures. 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, together with Fraunhofer IGD, IMBT and IOSB, we are developing an optoacoustic imaging sensor to support underwater work in poor visibility conditions. The aim of the TAUWIS project is to develop a semi-autonomous underwater inspection system that is equipped with various sensors to record the condition and position of objects in the water.

In the field of water management, for example, we are involved in the TETRA project, which aims to provide tools and methods for AI-based projects in water management. We will be focusing in particular on monitoring the water quality of rivers and the restoration of rivers. The SOWEKI project is developing an AI-based platform to synergetically optimize energy and resource management in drinking water infrastructures. The topic of flash floods has become relevant again, so we are very active in this field. We also work in the field of aquaponic systems, especially with partners based in China.

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 and infrastructure are available for client-specific projects such as integrating new sensors, collecting data in real environments, or validating sensors and components in the department's test tanks.

The department runs two fully operational and field-tested ROVs. These 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 versatile 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.

Spotlight activity

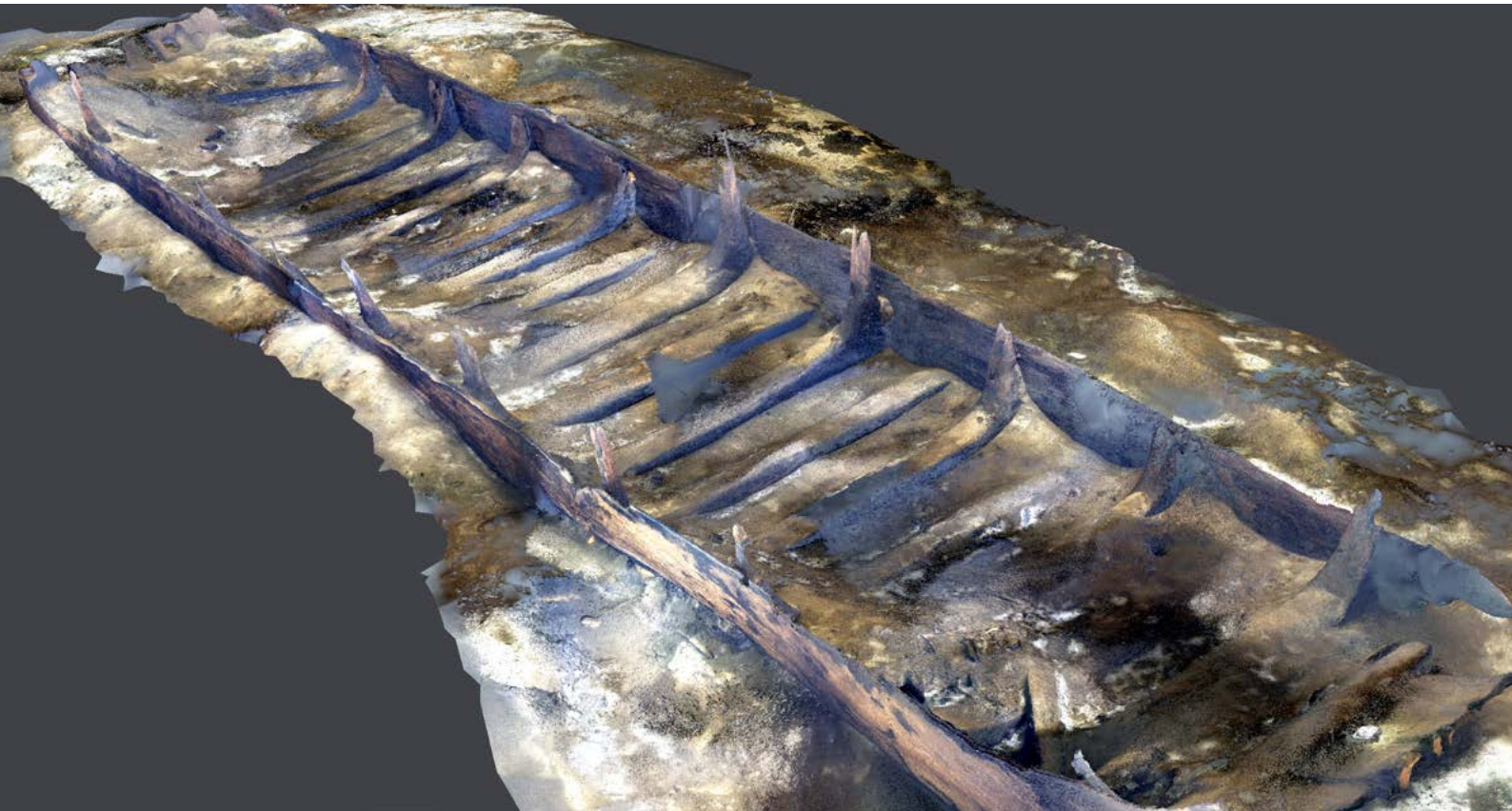
Underwater archaeology: 3D-reconstruction of a medieval ship using photogrammetry

For more than 700 years, a cargo ship—also known as a barge—lay undiscovered but well preserved at the bottom of Lake Arendsee in Saxony-Anhalt. During the investigation of the barge, led by the State Office for Heritage Management and Archaeology Saxony-Anhalt, UWR supported the mission with an underwater robot, equipped with an optimized camera, and photogrammetry expertise.

The resulting 3D-photogrammetry model of the medieval barge is based on over 7,000 images taken by our ROV. More than 185 million individual surfaces were assembled on a special GPU server. Our model provided new insights for archaeologists, who previously had little knowledge about the construction and functioning of high medieval inland vessels.

However, UWR's underwater robotics solutions supported the investigations in Lake Arendsee in many other ways as well: for example, they guided divers to their mission targets, monitored them in poor underwater visibility conditions, and assisted the dive supervisor in documenting the dive.

Picture of the 3D photogrammetry model of the medieval barge in Lake Arendsee.



HAI | Human-AI Interaction

We design the interface between humans and AI systems.

HAI

Head of department

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Research groups

- Decision Support Systems
- Perceptual User Interfaces
- Interactive Systems
- Explainable AI

iosb.fraunhofer.de/HAI

Research areas and expertise

The interaction between humans and AI systems determines the market success of many products. The Human-AI Interaction department researches and develops cross-sectional AI assistance services and interaction functions that enable optimal, intuitive and proactive cooperation. The department was formed in 2024 from the former Interactive Analysis and Diagnosis (IAD) department. Since then, we have focused on the interface between humans and AI, covering the entire technological spectrum: from collecting and annotating training data to training and explaining AI models to integrating innovative interaction modalities such as speech, gestures, augmented reality and virtual reality.

The focus is always on people. Our systems adapt to the intentions, context and situation of the users. The goal is human-machine cooperation that is not only reactive, but also proactive, user-centered and trustworthy.

Applications and products

The Human-AI Interaction department offers cross-disciplinary expertise that is in demand across many industries. Our research and development can be divided into three central areas:

- Perceptual user interfaces: Assembly assistants, robots and automated vehicles are advanced AI systems with interfaces to humans. Camera-based and multimodal detection of the user and their context form the basis for assistance with intuitive forms of interaction. Activity recognition and situation modeling enable proactive assistance functions.
- Applied Explainable AI: Trust in AI comes from traceability. Our methods and tools for explainable AI ensure that hypotheses become reliable, and decisions made by expert systems and autonomous applications remain transparent.
- Interactive Systems: We use innovative input and output methods—from virtual reality environments and touch interfaces to collaborative visualization systems—to develop tools that bring humans and AI together seamlessly in complex decision-making processes.

Infrastructure and lab facilities

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) to evaluate and develop methods for driver and passenger assistance. In addition, we run a seating buck unit to demonstrate our monitoring and assistance systems in a mobile setup that consists of a driver's seat, a steering wheel and multiple displays.

We operate a laboratory where we analyze human activities and test new ways for humans, robots, and other technical components (e.g., tools) to collaborate 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.

HAI's KALLE research vehicle puts the focus on in-cab-in monitoring and activity recognition.

Spotlight activities

KALLE research vehicle—human-AI interaction in automated vehicles
One example of our work in the field of perceptual user interfaces is the KALLE research vehicle (Karlsruhe Road Lab for Level 3 Evaluation). It is used to study the behavior of drivers in automated vehicles.

KALLE is based on a Mercedes EQS and is equipped with state-of-the-art sensor technology, AI computers and a near-series interior. This facilitates the development and testing of new functions, test subject studies, and the evaluation of series systems under realistic conditions.

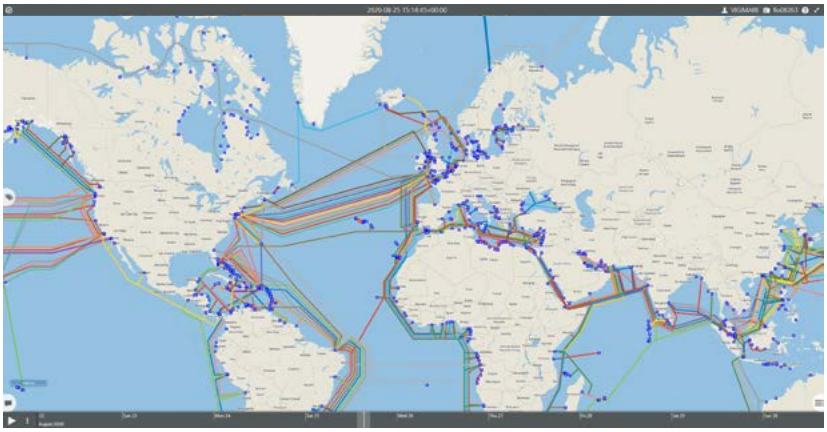
The AktiMeter, an AI-based system developed by Fraunhofer IOSB, recognizes when people turn their attention away from the traffic, for example when reading or sleeping, for how long, and what the passengers are doing. These insights are helping to make automated driving even safer and more user centered.

Interpreter for Multimodal Large Language Models—Explainability for complex AI systems
While KALLE shows how we capture people's perceptions and behavior when interacting with AI, our work in the field of Applied Explainable AI is dedicated to building trust.

With the Interpreter for Multimodal Large Language Models (MLLMs), we have developed a novel method that makes complex language-image models comprehensible. The approach combines object recognition, semantic segmentation and Shapely-based attribution to show which specific visual and linguistic elements led to a particular result. These visually presented explanations help identify erroneous correlations, increase transparency and support regulatory requirements. The MLLM interpreter is thus making an important contribution to trustworthy, responsible AI.

VIGIMARE—Interactive situation pictures for maritime safety
A third example from the field of interactive systems shows how humans and AI interact in safety-critical environments. In the EU joint project VIGIMARE, we are developing a system that helps operators protect critical underwater infrastructure—such as data and energy cables or gas pipelines—against physical, cyber-physical and hybrid threats.

At its core is a shared, near real-time situation picture that integrates data from sensors, satellites, historical sources of disruption and human reports. The central platform is Fraunhofer IOSB's Digital Situation Table (DigLT), which enables distributed work, 2D/3D analyses and dynamic timeline visualization. Supplemented by AI-supported anomaly detection and hybrid approaches combining data analysis and expert knowledge, the result is a powerful early warning and decision support system.



Overview of submarine cables on the digital situation table for monitoring in the VIGIMARE project.

OBJ | Object Recognition

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

Head of department

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Research groups

- Object Recognition in Sensor Networks
- Trackers and Tracker Assessment
- Heterogeneous Hardware Structures
- Video Content Analysis
- Object Recognition in 3D Sensory Data

iosb.fraunhofer.de/OBJ

Research areas and 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 working 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 recent innovations in this field is THS®, short for Target Handoff System.

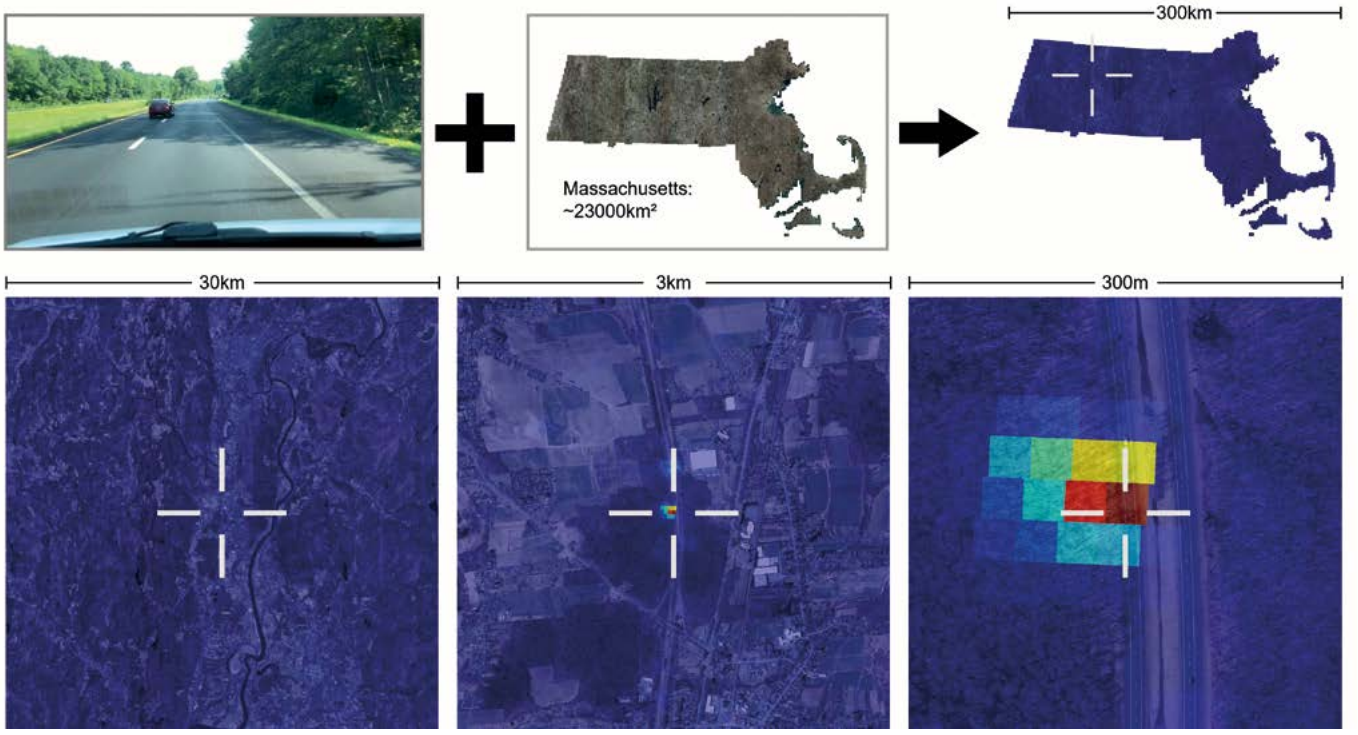
Infrastructure and lab facilities

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.

The transition in computer vision research from classical to learned methods across diverse applications requires the ability to store and process large amounts of data at scale, particularly for the compute- and data-intensive training of deep learning models. We established the Learning Lab at OBJ, a high-performance, multi-node computing and data platform consisting of modern Graphics Processing Units (GPUs), storage and networking to meet the needs of our cutting-edge research in this field.

Spotlight activity

Visual geolocalization
Visual geolocalization (VGL) concerns the problem of determining the geographic location and orientation of a camera by matching its images against a geographic model of the world. VGL can be used as an alternative to global navigation satellite systems (GNSS)



The geolocation of a street-view photo (top left) is determined using only its visual information by matching it against a database of aerial imagery of the search region (top center). The prediction not only covers state-sized search regions but is robust to real-world scenarios (with different weather and lighting conditions, image noise, seasonal changes) and yields correct, unique geolocations in the majority of all considered query images.

which are prone to jamming and spoofing attacks, typically only attain an accuracy of a few meters and are not applicable post-hoc, for example on images from online sources. A precise measurement of the geographic pose is a prerequisite for many use cases:

- allowing drones and other unmanned aerial vehicles (UAV) to behave autonomously even in GNSS-denied environments,
- integrating the location of different agents such as ground-based vehicles or personnel and aerial platforms into a centralized, geo-referenced representation for mission planning and oversight in GNSS-denied environments,
- acquiring and verifying open-source intelligence (OSINT) from online sources such as social media, where images are often uploaded without information on their geographic location.

At OBJ, we are particularly concerned with using satellite or aerial imagery as a representation of the world against which images from a query camera are localized. Such reference data are available at large scale and in high resolution, often for free or at low cost, and provide a dense model of the world in a geographic reference frame. In recent years, we have conducted ground-breaking research in this field that for the first time allows camera images to be localized in search regions spanning entire states (>10,000 km²) with predictions of sub-meter accuracy using only the visual information provided. Our state-of-the-art methods rely on machine learning models trained on our large-scale datasets and compute clusters to correlate the information in the query and reference views. This makes it possible to overcome the stark differences in perspective and scale and find unique matches between them. We are integrating this research into different platforms, including UAVs and systems providing a common operating picture (COP) for spatially aware decision-making processes, and are thereby addressing the need for precise determination of geographic positions, particularly in GNSS-denied environments.

SZA | Scene Analysis

Advanced geospatial analysis and tactical decision support systems enable rapid terrain evaluation for tactical operations in complex environments.

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Research groups

- Image Interpretation
- Geo Intelligence
- SAR Image Analysis

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Research areas and expertise

We develop advanced methods in Intelligence, Surveillance and Reconnaissance (ISR) that efficiently process and exploit data acquired from airborne and spaceborne platforms. These capabilities include segmentation, classification, change detection and multi-sensor data fusion, which together support robust and timely mission insights. Our core expertise lies in pattern recognition and scene reconstruction for remote sensing applications. By leveraging these techniques, we enable detailed analysis of complex environments and contribute to the creation of geospatial digital twins, thus facilitating enhanced situational awareness and informed decision-making.

Applications, products and services

AI-enabled image interpretation capabilities integrate heterogeneous airborne and spaceborne ISR data into mission-relevant intelligence products, emphasizing robust object detection within large satellite datasets. Complementary methods, such as AI-driven hyperspectral compression and targeted image analysis, ensure reliable exploitation even under operational constraints—including countermeasures such as camouflage and the need for performance-critical preprocessing. We employ regression-based models to evaluate atmospheric obscurants, both as visibility-reducing factors and as tactical indicators of impacts or movement. We address the dramatically increasing demand for training data by generating high-quality synthetic sensor image data for optical, infrared and Synthetic Aperture Radar (SAR) sensors. We automatically generate scene reconstructions from wide-area airborne laser-scanning data and photogrammetric point clouds. In active radar remote sensing, which remains effective regardless of weather or time of day, our expertise includes interferometry-based ground deformation measurements and AI-powered analysis of SAR data, with a special focus on applications within the New Space sector.

Our solutions support urban heat island mitigation and adaptation through advanced thermal simulations. We also analyze multimodal airborne and satellite imagery using state-of-the-art machine learning-based classification techniques to provide commercial insights and enhance disaster response. Additionally, we leverage geospatial data to enable informed tactical decision-making, as detailed in the following section.

Spotlight activities

Position Selection Assistant
The Position Selection Assistant (German: SWA – Stellungswahlassistent) is our tactical decision support system, designed to accelerate land forces' decision-making processes by means of automated terrain evaluation. The system identifies suitable positions by analyzing own weapon and enemy conditions.

The assistant can effectively operate with inverse attack directions to identify favorable enemy positions, thus supporting maneuver planning and threat assessment.

Our system requires digital terrain and surface models with a resolution of a few meters, supplemented by vector data. Systematic investigations have confirmed the global availability of sufficient data quality for worldwide deployment.

Position Selection Refinements
Following comprehensive field-testing campaigns, significant enhancements have been implemented to improve tactical applicability. Key developments include the analysis of rear operational areas and the implementation of local weighting systems for operations within constrained geographical areas. These refinements enable more nuanced position evaluation when forces have to operate in specific terrain sectors, providing relative position quality assessments even in globally suboptimal areas.

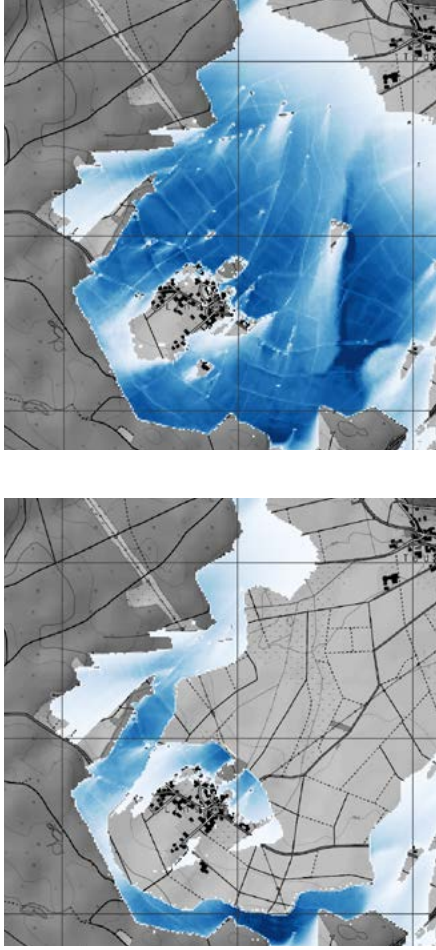
User feedback has driven improvements in infantry-specific requirements, particularly with regard to covered withdrawal routes and transition zones. The system now identifies areas offering both maximum concealment and optimal fields of fire within defined distances, both of which are crucial for medium forces and infantry operations.

Using AI to Estimate the Position Evaluation Map
Machine learning approaches have been developed to accelerate the most computationally intensive element of terrain analysis: total viewshed calculation. A fully connected multi-layer perceptron network estimates maximum visible distances along sight rays, achieving significant performance improvements with factor-29 acceleration for large-scale calculations.

The neural network demonstrates accuracy within ± 250 meters for observer and target height variations, enabling 99.9% reliability when combined with appropriate safety margins. This breakthrough, documented in peer-reviewed publications, maintains all existing weighting and correction capabilities while dramatically reducing computational requirements for operational deployment.

MilitAR-Sandbox
The MilitAR-Sandbox serves as an innovative demonstration platform for the Position Selection Assistant, making it tangible and comprehensible for users. This demonstrator enables users to observe the real-time effects of parameter adjustments and terrain modifications while gaining an intuitive understanding of algorithmic responses to different terrain formations.

The technical system combines proven military sand table concepts with modern technology. A 3D camera captures sand surface topography, which our algorithms evaluate as terrain models, with results projected back onto the sand surface through an integrated projector. The system includes coordinate grids, elevation contours and intermediate result visualization for enhanced user understanding. Every visitor demonstrates rapid comprehension improvement after hands-on interaction, with troop testing sessions contributing to algorithm refinement.



Position Evaluation Map (top) and refined version (bottom). Deeper blue indicates better position evaluation. Grid size is one kilometer.

Position Selection Assistant recommendations in blue on the sand topography.

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.

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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 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 meet 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 generate hints for a human decision-maker. Furthermore, we have transferred and optimized various algorithms to the maritime domain, e.g. for search and rescue applications.

Infrastructure and lab facilities

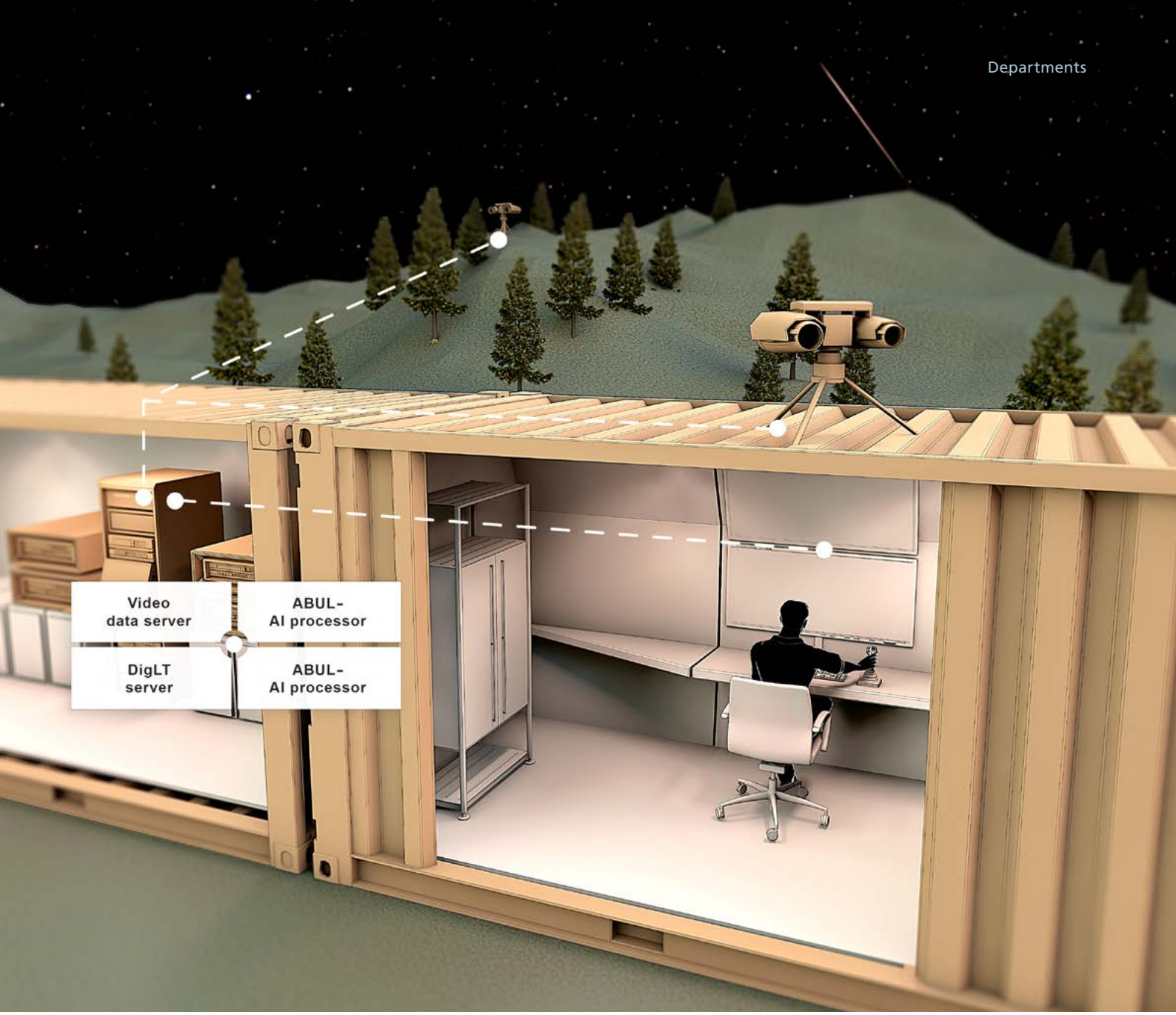
ABUL development, setup and test lab.

Spotlight activity

AI-supported property protection for the Bundeswehr

The KIOBS surveillance system was developed as a means of providing effective protection for Bundeswehr facilities and critical infrastructure using high-performance video sensors. Given how threat scenarios have changed since 2022, especially as a result of Russia's attack on Ukraine, maintaining security on home soil has become a matter of vital importance.

KIOBS uses state-of-the-art high-performance sensor systems to monitor extensive areas even when visibility is limited. We have developed a video analysis system based on the real-time video evaluation software ABUL. This system contains other components



Video analysis system for asset protection based on the established systems ABUL, CSD, DigLT, i2exrep, and RecceMan.

developed by Fraunhofer IOSB that are used by the Bundeswehr in its surveillance tasks. It relies on deep-learning algorithms to detect and track people and vehicles, even in adverse weather conditions and low visibility.

The system simultaneously analyzes multiple full-HD video streams in the visual and thermal infrared range and identifies defined threat scenarios in real time. The software helps the human system operator evaluate the video footage by actively guiding the cameras along patrol routes. AI algorithms detect alarm scenarios such as suspicious group movements or the unauthorized entry of persons or vehicles into sectors under surveillance. When an alarm is triggered, the system determines the geocoordinates and plots them on a digital map, allowing the operator to respond quickly and with pinpoint accuracy.

Particular attention is paid to efficient data processing. Only detected alarm events are saved in the long term; these are stored as video clips on a NATO-compliant Coalition Shared Data Server, allowing them to be shared with partner organizations. In future, the system could be enhanced by integrating drones as additional sensor carriers, thus facilitating surveillance of hard-to-see areas. The system will also be able to detect and track approaching drones using our proven camera-based drone detection processes.

VBV | Variable Image Acquisition and Processing

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

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About

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

iosb.fraunhofer.de/VBV

Research areas and 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 formed on the sensor cannot be interpreted by the naked human eye, but when adequately processed by the optimized algorithms, can yield results that are superior to those of a comparable conventional system.

Applications and products

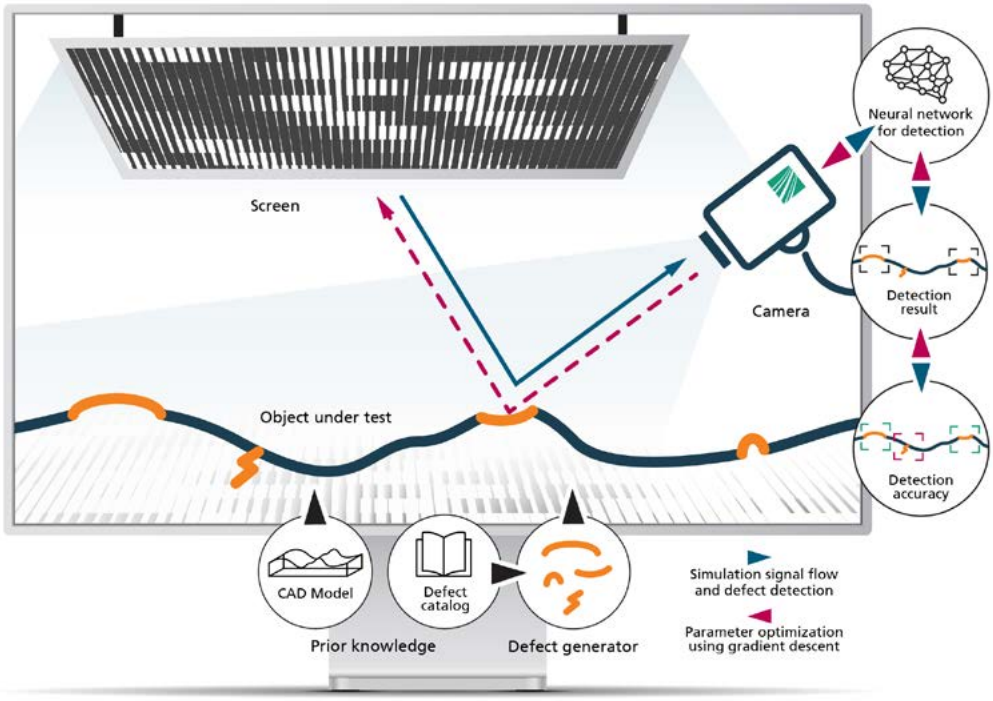
Our research activities cover various artificial vision applications. Tackling challenging open questions in the field of automated visual inspection is one of our core topics. For example, we orchestrate multiple light sources to acquire a set of images where the object under test is sequentially illuminated 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, e.g. for detecting contaminants in food products using anomaly detection or for synthetically increasing the resolution of images captured with a low-quality microscope lens.

Spotlight activities

OptiMus—learning optimal screen patterns for deflectometric surface inspection

OptiMus is an end-to-end, differentiable optimization framework for single-shot deflectometry of specular surfaces. Instead of heuristic sinus stripes, it computes a single object-specific, optimal screen pattern and tuned detection model parameters from the CAD geometry to maximize defect detection accuracy. The full imaging chain—pattern display, reflection on the 3D surface, image formation in the camera and neural network-based defect detection—is modeled with differentiable ray tracing and deep learning (PyTorch), enabling gradient-descent co-optimization of optics (pattern) and algorithms (see figure top right).



Optimization pipeline for finding object-specific optimal illumination patterns and system parameters.

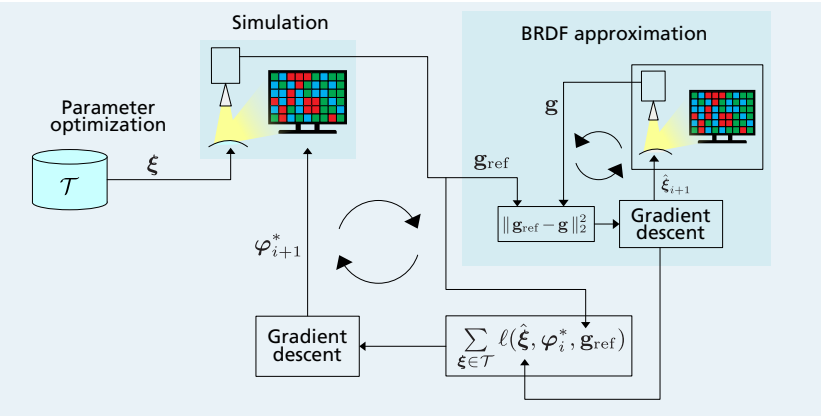
Middle: Pipeline for reconstructing the unknown BRDF of a test object by means of inverse rendering.

Bottom: Simulated reconstruction experiments. With the optimized pattern, 15 iterations (vs. 50 iterations for the random pattern) are sufficient to create a close approximation of the reference image (last column).

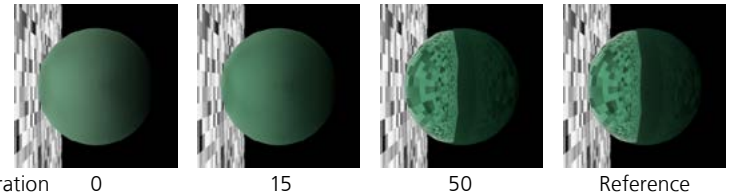
Synthetic parameterized defects are procedurally injected on the CAD model to generate training and evaluation data. The approach targets inline-capable inspection by extracting maximal information from a single exposure. Key challenges (pattern dimensionality/overfitting and real-world disturbances) are addressed via compact pattern bases or low-res upscaling and by simulating sensor noise/perturbations. Simulation-based results already demonstrate that the approach yields patterns and also inspection results that are superior with respect to the classic fringe patterns.

Fast BRDF approximation without mechanical angle scans

The BRDF (bidirectional reflectance distribution function) describes how light is reflected from a surface for given incident and viewing angles, and is used for realistic rendering, remote sensing and material identification. We have developed an inverse-rendering approach to approximate a material's BRDF without mechanical angle scans. A programmable display acts as a high-dimensional light source; a camera captures the object's reflections. Using a differentiable renderer, principled BRDF parameters (e.g. metallic, specular, roughness, base color) are recovered by gradient descent to minimize the mean squared error (MSE) between rendered and reference images (see middle figure). The illumination pattern is co-optimized end-to-end across training BRDFs, yielding a pattern that maximizes reconstruction efficiency. A two-level optimization estimates BRDF parameters for each sample while updating the pattern via automatic differentiation. Simulations show that the learned pattern ignores occluded regions and accelerates convergence with lower image/parameter errors than random patterns (see bottom figure). The method promises faster, practical BRDF measurement for graphics, material identification and automated inspection.

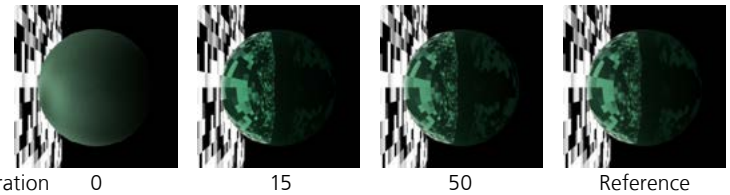


Renderings based on BRDF approximation using random pattern



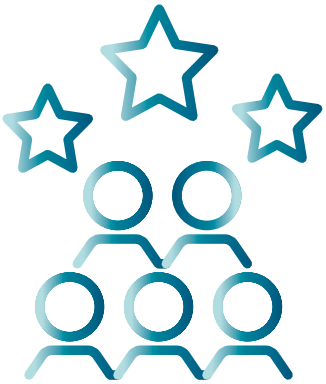
Iteration 0 15 50 Reference

Renderings based on BRDF approximation using optimized pattern



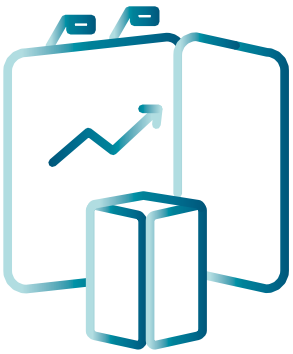
Iteration 0 15 50 Reference

Facts and figures: 2024–25 in numbers



>260
committee memberships

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



72
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.

117
teaching activities

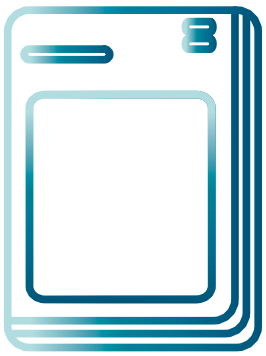
such as lectures, seminars, tutorials and practical courses at different academic institutions were performed by our staff.

≈190K
website visits

In 2025, our institute's web pages received approximately 190,000 external visits, originating from about 140,000 unique visitors. That's about 19 percent more than in 2024.

27
awards and prizes

Our scientists and their publications have been awarded numerous awards and prizes.



>600

journal and conference papers

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

28

doctorates

Twenty-eight researchers working at Fraunhofer IOSB passed their doctoral examinations in 2024 and 2025.

>2,000

participants

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

19

patents granted

Applications for a further 28 patents have been disclosed in 2024 and 2025. In addition, four 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-2026

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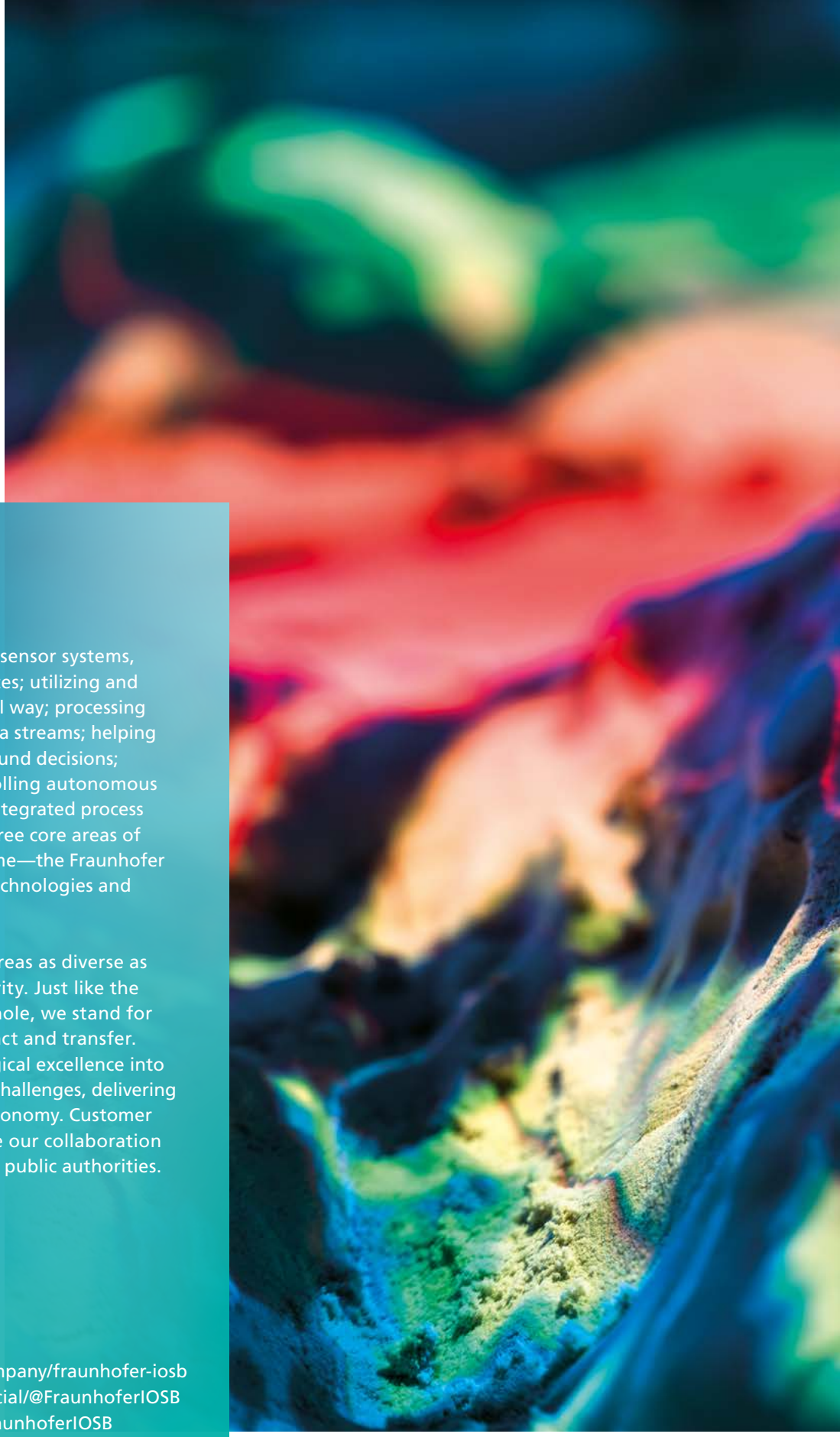

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Developing new types of visual sensor systems, including specialized laser sources; utilizing and connecting sensors in an optimal way; processing and evaluating the resulting data streams; helping people, on this basis, to make sound decisions; enhancing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

Our expertise comes to use in areas as diverse as automation, inspection or security. Just like the Fraunhofer-Gesellschaft as a whole, we stand for applied research driven by impact and transfer. We turn scientific and technological excellence into reliable solutions for real-world challenges, delivering value for society and a strong economy. Customer orientation and reliability guide our collaboration with partners from industry and public authorities.

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