Fraunhofer
IOSB

FRAUNHOFER INSTITUTE OF OPTRONICS, SYSTEM TECHNOLOGIES AND IMAGE EXPLOITATION

10 YEARS OF
FRAUNHOFER IOSB
A young institute with a long history

ANNUAL REPORT
2019/2020

Dear readers,

The Fraunhofer Institute of Optronics, System Technologies and Image Exploitation was established ten years ago, on January 1, 2010. Despite being a young institute, we can nonetheless look back on a long and successful history. This is because Fraunhofer IOSB is the product of a merger between two previously existing institutes: Fraunhofer IITB and FGAN-FOM.

Our first major milestone presents an ideal opportunity to preface this report with a special anniversary section devoted to tracing this process of development. We take a quick look at our roots, recall the events and circumstances attending the merger, and outline some of the key ideas and success stories accompanying the first ten years of Fraunhofer IOSB. Each one of these is testament to the huge potential stored within the comprehensive and unparalleled range of expertise that was created by the merger. On the strength of these resources, we have already achieved major technological advances in many of these fields.

This introductory section is followed by the customary report – in a new and substantially more compact form – covering the reporting period of 2018/2019. This contains basic facts and figures about our institute, its structure and its place within the Fraunhofer-Gesellschaft. Selected highlights from our wide range of activities illustrate the dynamism and versatility of our institute. We are much in demand as a partner in our specialist fields and as a player who helps shape future technological developments in areas such as security, defense, Industrie 4.0 and digital infrastructure. The report concludes with a presentation of our business areas and departments.

To give at least a flavor of the full scope of our activities, we deliberately report on a large number of individual topics and projects. These are therefore presented in a concise and condensed manner. We trust that you will understand this in the spirit intended: as a stimulating read – and, above all, an invitation to enter into dialogue with us!

Karlsruhe, Ettlingen, Ilmenau, Lemgo and Görlitz
February 2020

Prof. Dr.-Ing. habil. Jürgen Beyerer

FGAN

RESEARCH SOCIETY
FOR APPLIED
NATURAL SCIENCES

1971
The group becomes an independent
group within the Research Institute
of Radio and Mathematics (FFM)

1964
Research group at Karlsruhe
University's Institute of Communication
Processing and Transmission starts work

FIM

1974
The group emancipates from FFM and
transforms into the Research Institute
of Information Processing and Pattern
Recognition (FIM) located in Ettlingen

1959
At the University of Tübingen's
Institute for Astronomy, a group starts
with basic and applied research in optics

FFO

1973
The group is incorporated into FGAN
as Research Institute of Optics (FfO),
located at Kressbach Castle, Tübingen

1957
Start of operation of the
Institute for Oscillation
Research (ISF) in Tübingen

1967
Integration of ISF into
the Fraunhofer-Gesellschaft

1973
Two divisions originate:
Information Processing, or

IITB-IV

ISF

1970
Change of name to Institute
for Information Processing in
Technology and Biology (IITB)

1979
Change of name
to Institute for
Information and
Data Processing
(IITB)

1968
Relocation of ISF to
Karlsruhe Waldstadt

and the Data Processing
division, or

IITB-DV
1973

FRAUNHOFER

FRAUNHOFER-GESELLSCHAFT
FOR THE ADVANCEMENT OF
APPLIED RESEARCH

2000
Relocation of FOM to the former Rheinland-Kaserne in Ettlingen

2006/2007
Evaluation by the German Science Council

FOM

2009
Effective from August 17, FGAN is integrated into the Fraunhofer-Gesellschaft

1999
FfO and FIM are merged to form the Research Institute of Optronics and Pattern Recognition (FOM)

2010
IOSB
With effect from January 1, FOM and IITB merge into Fraunhofer IOSB

1996
Opening of the representative Office in Beijing

IITB

1995
The IV and DV divisions are merged. Also the Application Center for Advanced System Technology (AST) is founded in Ilmenau

2009
The Competence Center for Industrial Automation (INA) is founded in Lemgo

2006/2007
Evaluation by the German Science Council

Prof. Dr.-Ing. habil. Jürgen Beyerer has been Executive Director of Fraunhofer IITB/IOSB since 2004. At the same time, he was appointed Chair of the Vision and Fusion Laboratory, Department of Computer Sciences, Institute for Anthropomatics and Robotics, at the Karlsruhe Institute of Technology (KIT).

Prof. Dr. rer. nat. Maurus Tacke took over as Executive Director of FGAN-FOM in 2000. After the merger, he headed up Fraunhofer IOSB alongside Jürgen Beyerer until retiring in 2013. He teaches physics at the University of Würzburg.

"IN THE END, IT ALL COMES DOWN TO TRUST"

Jürgen Beyerer and Maurus Tacke steered Fraunhofer IITB and the Research Institute of Optronics and Pattern Recognition FOM – at the time part of the Research Society for Applied Natural Sciences (FGAN) – through the merger that formed Fraunhofer IOSB. In this interview, they look back on the events.

When were you confronted with the idea of a merger?

Jürgen Beyerer: I joined Fraunhofer IITB in March 2004, and learnt in the fall of 2004 that an evaluation by the German Science Council was in the offing. Hartmut Wolff, at the time undersecretary at the German Federal Ministry of Defence (BMVg), was the driving force behind this process. In view of how close IITB and FGAN-FOM were in terms of content and locations, he saw the possibility of merging the two.

Maurus Tacke: I saw the signs of the impending merger even earlier than that. Soon after I joined FOM in 2000, I registered that Mr. Wolff sought to provide base funding to Fraunhofer IITB out of the defense ministry's budget, because he already funded substantial defense-related activities there. A merger seemed to be a logical step in this direction. The two institutes had a lot in common – both in terms of research focus and the low level of base funding they received from the ministry of defense. IITB received none, and FOM received less than other research institutes in the defense sector because its strongest

growth happened to coincide with a base funding freeze. So, unlike the two other FGAN institutes, we were already strongly acquainted with the world of contract research with its uncertainties and need for project acquisition.

What was your reaction?

Beyerer: Straightaway, I was delighted with the idea of a merger. Together, we would be able to cover a vast range of topics, from the physics of signal generation to the way humans and machines use the information contained in these signals. At the time, FOM's spectrum leaned more towards physics. IITB took it up from there to address everything from computer science to human-machine interaction and questions about the interoperability and availability of this data. Just imagine the possibilities that would come of combining this spectrum from end to end in one institute! No one else in Europe offered such a broad spectrum, so we would have a unique selling proposition.

> Beyerer: "Straightaway, I was delighted with the idea of a merger"

Tacke: I liked the idea too. Before joining FOM, I had headed up a department at the Fraunhofer Institute for Physical Measurement Techniques IPM in Freiburg. I soon saw the structural disadvantages in the FGAN, which had been working exclusively for the ministry of defense. The more open Fraunhofer model was in many respects preferable. The only thing I found problematic about FGAN's integration into Fraunhofer was that it was up in the air for so long. I had recently been appointed chairman of FGAN, so I had to make sure that it would come out of the process unscathed, even if the integration might not come to pass. This is why we worked separately until the moment the merger was definite.

What happened after 2004?

Beyerer: The German Science Council carried out its evaluation in 2006. I advocated recommending a merger for the reasons mentioned earlier. In its report in late 2007, the German Science Council made an unequivocal recommendation to integrate FGAN into Fraunhofer and to merge our two institutes. Then it was up to the ministries and Fraunhofer to decide if they would

act on this recommendation. The integration took place in mid-2009 and the merger took effect at the beginning of 2010.

Tacke: However, this was preceded by protracted debate. Fraunhofer and the German Federal Ministry of Education and Research (BMBF) voiced concerns that quality might suffer as a result. I suspect that an ingrained aversion to supporting military research also played a role here. Ultimately, though, the Science Council's verdict persuaded everybody that the merger would be a good thing. On the other hand, some at FGAN feared that working along the lines of the Fraunhofer model would bring on too much economic pressure, with the thinking being that this would strip us of our academic freedom and scientific autonomy.

What kind of relationship existed between the institutes and yourselves?

Beyerer: We were always aware of each other's existence, of course. I was at FOM with former IITB director Hans-Achim Kuhr in 2004 for my inaugural visit. When the talk turned to the merger, we debated it, and there were certainly some opposing viewpoints. We held many discussions about the pros and cons and grappled with the question of how it could be done. Then, when it became clear that the integration and merger were going to happen, the question was how do we come together on an equal footing without this feeling like a takeover? The departments had their reservations. After all, they had been rivals to some extent in the past.

Tacke: Despite there having been some collaboration and joint projects, the feeling of being competitors prevailed because both institutes were working in the defense market and in image exploitation.

Beyerer: And suddenly there we were, sat at the same table, talking about how to work together in a future joint institute, about how to bridge divides. In the end, it all comes down to trust. It is my firm conviction that the merger was only successful because the two of us, as persons, managed to work well together.

Tacke: When the decision stood, it was clear that we would have to unite this house. And we did exactly that – together.

Beyerer: Yes, once the decision to integrate and merge had been made, we both put the pedal to the metal and worked on the structures and on building trust between our people.

What did this work toward the merger entail?

Beyerer: We started off with regular strategy seminars, which are still held today. And we launched initiatives with a communicative touch to build trust – for example, a cooking course that paired one person from FOM with another from IITB for the two to cook as a team. It was during this phase that ideas for IOSB's structure emerged – that the specialist departments ought to be the institute's actual constituents, and that the heads of department ought to remain second-tier managers with the authority to embed their departments in the science and engineering communities and take budgetary responsibility. At the same time, we decided to set up business areas to present a unified, readily identifiable face to the markets. However, the departments support this added structure without being subservient to it. To both of us it was important to involve all the department heads in this process so that everyone can get behind the result.

And how did the workforces feel about it? Wasn't there tension?

Tacke: It gradually became clear to everyone that a merger was growing more and more likely. Thanks to my history at Fraunhofer, I was able to explain to the FOM staff what was in store for them. I had the impression that they accepted it – they didn't break out in cheers, but they weren't overly concerned either. There were some reservations in the works council that the pressure might be too great and that there would be financial drawbacks. And some in IITB feared that defense research would dominate. But both of these concerns were put to rest over time.

Beyerer: I never had any hard arguments pointed out to me. People were curious. Some may have had a concern or two, for example, if their jobs were going to be relocated to Ettlingen. The works council wanted a severance scheme, but we explained to them that this merger is not at all about downsizing. It was about two successful institutes seeking to join forces to stride forward into the future even more vigorously. Growth could certainly be part of this.

So did the newly-formed IOSB get off to a good start without any teething troubles?

Tacke: Absolutely. We had enough seed funding to pursue market-driven projects that would move us even closer to the Fraunhofer world. And the benefits of our structure soon became apparent. The business areas provided anchor points in various fields of application for the departments, so they had the support they needed when they set out to explore new use cases. The merger turned out to be a success even though the base funding from BMVg was not reorganized as we had hoped it would be.

Beyerer: From day one, we have been working within a complex organizational framework, which – on top of that – also varies from site to site. But as you can gather from the institute's positive development, we have managed to make the best of it. What has always been important to us is that we refuse to let surrounding circumstances hinder our research work, and that we pool our strengths, focusing them in a goal-driven way to jointly achieve the best possible results.

Are there any projects or topics that highlight how the merger has created opportunities in science and engineering?

Tacke: Cross-pollination and mutual support are commonplace – for example, when one department provides data that proves another department's project is important and worthy of funding. On the other hand, in my experience large cross-departmental projects are more the exception than the

> # Tacke: "The more open Fraunhofer model was in many respects preferable"

rule. This is to be expected when the dividing lines between departments and groups are set properly in terms of content. This way, individual units can work on a problem from end to end. It is tremendously helpful to be able to communicate in an atmosphere of trust within an interdisciplinary institute.

Beyerer: I see the synergy evident in underwater vision, for example. It is a hot topic at Ilmenau, Karlsruhe and Ettlingen, even if each site addresses different aspects of it. Another example is drone detection and defense. This would not have been possible without the collective expertise of the colleagues in Ettlingen and Karlsruhe. And looking ahead, I see the ministry of defense pursuing major long-term projects – Future Combat Air System, or FCAS, and Main Ground Combat System, or MGCS – where I believe our broad spectrum as an institute will be very useful indeed.

Speaking of looking ahead, what are your hopes and expectations for the IOSB's next ten years?

Tacke: I hope that the structure of base funding for defense research will become more coherent and systematic. The fact that we have managed to handle the situation without it negatively impacting our work is a great success. And things could be even better given an optimized funding and regulatory framework. Apart from that, I believe the institute is in a good position. I expect to see some nice and profitable results in the next ten years, without being able to say what exactly they will be.

Beyerer: Having a first-rate infrastructure at all sites is important. We are well on our way with various building projects. As far as content goes, I hope and expect that we will make visible and substantial contributions to the two major defense projects mentioned earlier and to the resolution of the challenges facing civil society. There are a number of topics for which I hope we will be the partner of choice and be able to maintain our competitive lead. Examples include embodied machine intelligence, digitalization in the context of industrial manufacturing and automation technology, and the question of how to turn artificial intelligence and machine learning into an engineering discipline.

This is a translated and (slightly) abridged version of the original interview with Prof. Beyerer and Prof. Tacke, which was led by Ulrich Pontes. The full interview in German can be found at

🌐 *iosb.fraunhofer.de/10-years-interview*

IDEAS AND SUCCESS STORIES

SUBMARINE DRONES FOR DEEP-SEA INSPECTION AND EXPLORATION

Lightweight, production-ready diving robots are able to operate independently and dive to depths of several thousand meters to collect observation data. These autonomous underwater vehicles (AUVs) could serve to inspect deep-sea cables, discover natural resources, locate sunken wrecks and simply reconnoiter the largely unexplored deep sea. However, there were only expensive, heavy and complex one-off products. This is why Fraunhofer IOSB researchers in Ilmenau and Karlsruhe set out to develop and test new designs.

They chose an open architecture where water flows through much of the structure. A very light shell made of syntactic foams provides buoyancy. Electronic components, impervious to pressure, are cast in watertight silicone resin. The researchers also drew on the institute's expertise in the areas of underwater sensors, sensor data fusion, environmental sensing, autonomous navigation and remotely operated underwater vehicles.

Their efforts culminated in **DEDAVE**, short for Deep Diving AUV for Exploration (see photo). Presented to the public in 2016, it is pictured here hovering above the Fraunhofer IOSB-AST test pool. Kraken Sonar, Inc., a Canadian company,

licensed DEDAVE and deployed it in 2017 to find several test models of a hypersonic interceptor aircraft called the Avro Canada CF-105 Arrow at the bottom of Lake Ontario. Canada stopped this aircraft's development in the 1950s for strategic reasons. All documents and components were destroyed. There is now a great interest in reconstructing the details of this historic project. The models' discovery attracted enormous attention and buzz in the media, particularly in North America.

Fraunhofer IOSB also took up the challenge of the Shell Ocean Discovery **XPRIZE**, a global technology competition launched in December 2015. The competition's goal was to invent highly autonomous yet affordable new technologies to map the ocean floor in great detail and to demonstrate their ability to do this. The ARGGONAUTS team from Fraunhofer IOSB developed tandems comprising lightweight autonomous surface vehicles and a swarm of torpedo-shaped diving drones. The only German entry among 32 competing teams, the ARGGONAUTS were one of the best five finishers.

CONNECTED AUTONOMOUS SYSTEMS IN HOSTILE ENVIRONMENTS

Autonomous, networked robots such as flying drones, unmanned ground vehicles (UGV) and semi-autonomous machines are predestined to tackle dangerous tasks such as reconnoitering hazardous or poorly accessible environments in the wake of an earthquake or an industrial accident in order to provide an accurate situation report. They can also clean up contaminants, sparing humans the need to work in areas with health hazards. But these applications present a host of technical challenges. The robots have to be able to navigate unknown and irregular terrain, extract information from a wide range of sensor data to provide a standardized situation report, and plan and execute complex motion sequences to perform manipulation tasks. They should also be able to cope with unexpected events and make independent decisions.

Fraunhofer IOSB has pursued many projects over the years to advance these technologies. One result is a **toolbox of algorithms** for localization, mapping, obstacle detection and motion planning. Another is a **retrofit kit for machinery** to equip standard tractors and excavators with autonomous functions.

IOSB.BoB, the "excavator without operator" (see photo), has been attracting attention at many demonstrations since 2017. In 2018, these efforts culminated in the founding of the Fraunhofer IOSB-led competence center **ROBDEKON** on robotic systems for decontamination in environments hostile to humans (cf. also page 24).

2011–

IDEAS AND SUCCESS STORIES

2018–

2020–

LASER TECH – A STRATEGIC ADDITION TO THE INSTITUTE'S PORTFOLIO

Since its inception, Fraunhofer IOSB's skill-set has covered most of the optronics evaluation chain: from signal generation, sensors, image acquisition, processing and exploitation up to user-oriented reports. On the other hand, the generation of light suitable for active sensor systems and other purposes such as optical communication did not belong initially to the research spectrum of the institute. With the head of the division Photonics and Optronic Systems poised to retire, the institute was able to follow through on the long-held strategic aim of appointing a laser specialist as division manager.

In April 2018, the physicist **Prof. Marc Eichhorn** took up the management position in Ettlingen and was appointed professor for optronics at the Department of Electrical Engineering and Information Technology of the Karlsruhe Institute of Technology (KIT). Immediately after, he began the establishment of a new science department devoted entirely to components and systems that generate and amplify light for optronics applications – the Department of Laser Technology (LAS). The institute's skill-set now covers the entire optronics chain.

ETTLINGEN AND KARLSRUHE – CONNECTED AT THE SPEED OF LIGHT

The tower on our building in Ettlingen offers an unobstructed view towards Karlsruhe – and thus the pre-requisite for a special cross-site experiment: a seven-kilometer laser measuring range to study optical communication in free space under real-world conditions.

The atmosphere causes scattering, refraction, dispersion, absorption and other interferences. Some of this is attributable to the physical properties of gases; but most is due to suspended particles, turbulence and the like. All interference impedes robust communication and limits bandwidths, which is why adaptive optics have to compensate for these disruptive factors. We started equipping the tower room to this end in 2017. The laser measuring range will be up and running around the time of the institute's tenth anniversary.

2014–

2011–
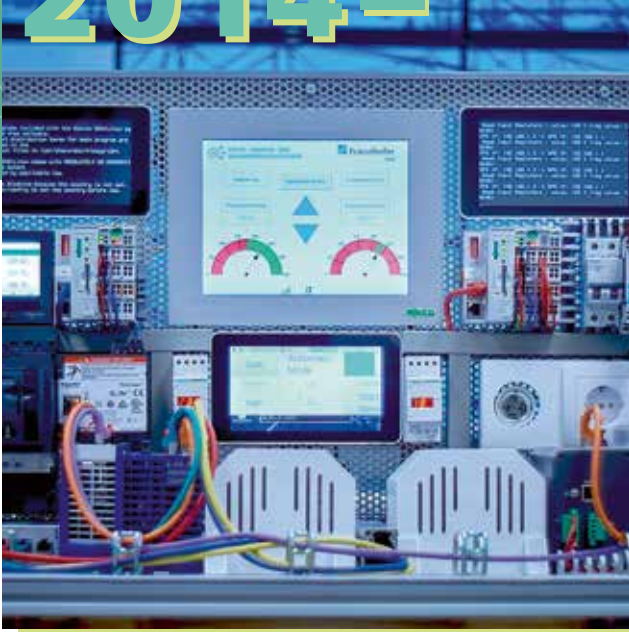
CYBERSECURITY TRAINING LABS

The digital transformation in our living and work environments makes us more vulnerable to cyber attacks. Our institute has been investigating IT security issues for many years. As part of an in-house research project launched in 2014, we started building a demonstrator to simulate and investigate real-world threat scenarios using standard components for production control. The IT security lab was received with great interest at the Hannover Messe in 2015.

Soon after, we began to hear of growing demand for comprehensive training to qualify specialists in this field. The Fraunhofer Academy, various Fraunhofer Institutes and associated universities of applied sciences heeded the call by setting up the Cybersecurity Training Labs. Their hands-on seminars for professionals have been very successful. Fraunhofer IOSB was instrumental in developing the concept behind these labs and is responsible for two of the six subjects on the training agenda: **cybersecurity in industrial production** at Fraunhofer IOSB in Karlsruhe and Lemgo together with the University of Applied Sciences Ostwestfalen-Lippe and **cybersecurity in energy and water supply** at Fraunhofer IOSB in Ilmenau and Görlitz with Fraunhofer IDMT and the University of Applied Sciences Zittau/Görlitz.

ENGINEERING AI METHODS FOR MANUFACTURING PROCESSES

Impelled by digitalization and rapid advances in machine learning, data-driven methods are becoming more important for manufacturing. Often replacing or augmenting modelling and knowledge-based approaches, these data-driven methods serve many purposes. They can help optimize individual steps in the workflow and control complex processes to minimize waste and maximize productivity. They can detect anomalies, enable predictive maintenance and optimize the logistics of complex supply chains. Computers can use sensors and actuators to learn how process parameters and outcomes are related. This enables engineers to develop and roll out 'immature' processes – that is, production processes that are not yet fully understood in terms of the physics or engineering.

Fraunhofer IOSB in Karlsruhe and Lemgo has realized artificial intelligence (AI) applications like this in many projects with industry. Seeking to take an even more systematic approach with an ideal infrastructure, we joined forces with Fraunhofer ICT and the Karlsruhe Institute of Technology to build the **Karlsruhe Research Factory**. Its mission is not limited to optimizing production steps and processes, but will go beyond to establish a comprehensive methodology for applying AI to industrial manufacturing. Our aim is to develop an engineering-based approach to reliably predict the operational behavior of manufacturing processes even in the planning phase.
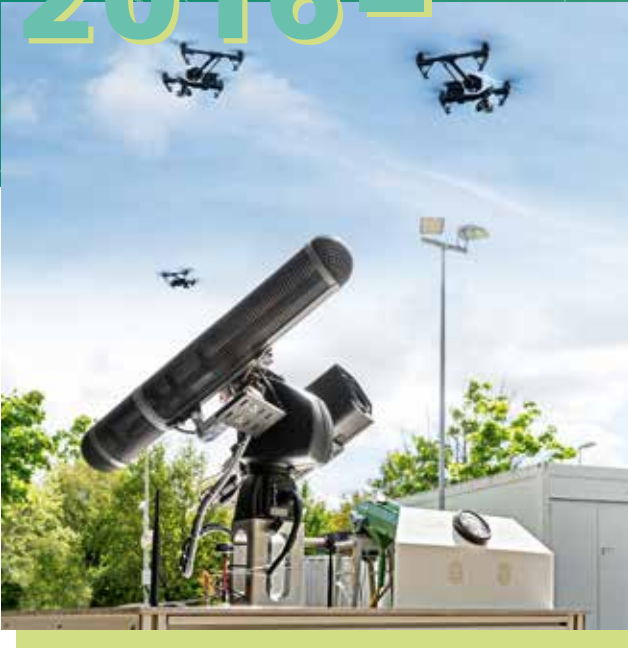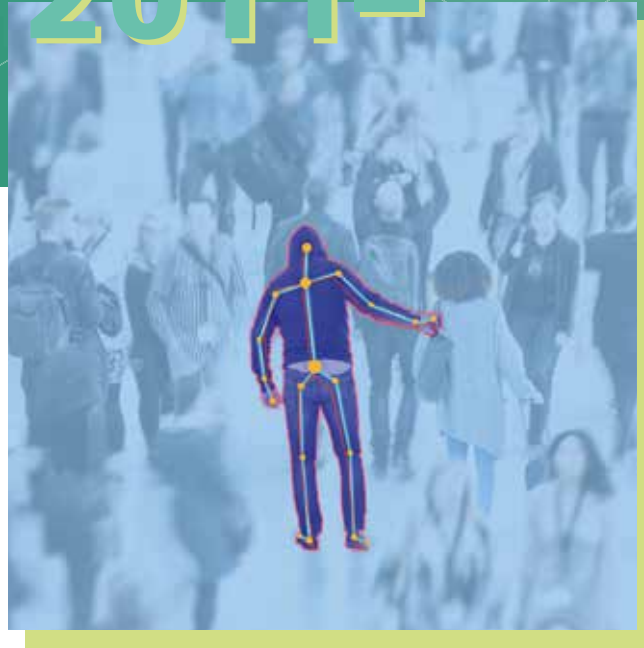
DETECTING AND DEFENDING AGAINST MINI DRONES

BETTER DATA PROTECTION WITH SMART VIDEO ANALYSIS

Miniature drones can be useful or a potential danger. Affordable, easy to operate and fast, these unmanned aerial systems (UASs) can endanger air traffic near airports. Attack scenarios are not far-fetched. It is high time to develop detection and defense systems that can reliably detect UASs to allow security forces to make informed decisions with sufficient reaction time.

Fraunhofer IOSB is pursuing various projects to investigate issues relating to detection, classification and potential defense measures. The institute has award-winning AI-based algorithms to distinguish between drones and birds in video images in real time. Since 2016, we have invested our own resources towards developing **MODEAS, a modular drone detection and assistance system**. Its distributed sensor stations detect flying objects in a multimodal way, for example, by using radar, detection of remote-control radio signals, high-resolution panoramic sensors, tele-zoom cameras and laser rangefinders. A stationary or mobile control center processes all data and presents it in a user-friendly format. The system references a database containing many drone models to identify the device. It also derives other parameters such as the payload from sensor data. This enables security forces to properly assess the threat potential and opt for the right response.

Privacy and data protection are growing concerns amid increasing process digitalization and in particular capturing of video data. We develop methods that ensure compliance with data protection regulations to alleviate these justified concerns and foster acceptance for such technologies. The underlying idea in our **privacy by design** approach based on the "need to know" principle is for systems to withhold certain information from the user if not needed, or to disclose it only in clearly defined cases. We can make surveillance systems mask certain areas based on the camera's exact position and line of sight. In medical care use cases where cameras serve strictly to monitor patients, these systems can replace images of marked staff with background images.

Human pose estimation and activity recognition algorithms, paired with digital abstractions of people filmed (see image), could take this a step further in the future. For example, the view of a hospital corridor on the monitor would be blacked out until the algorithm detects a person falling or lying on the floor. Live images of public places streamed to police operation centers could remain pixelated until the system detects suspicious patterns of movement that point to criminal activity.

HOLISTIC INFORMATION MANAGEMENT FOR SECURITY AND DEFENSE

The security context may be military or civilian, but in both use cases, sensors and information systems generate vast amounts of data. The relevant information has to reach the right decision makers quickly. And that requires a network of interoperable systems, connected across organizational and national boundaries. It also requires smart analysis algorithms and a user experience designed to help these people do their jobs effectively.

We have been working on corresponding standards for many years, for example, at the NATO level. We develop concepts and architectures and concrete hardware and software systems to put these standards into practice and operationalize collaborative processes such as Joint ISR (Intelligence, Surveillance and Reconnaissance) in the best way possible. This is how the idea of **Coalition Shared Data** (CSD) came about. It affords rights-based access to data (such as images, reports, streams, tasks) from arbitrary sites in near real-time. The system normally distributes only metadata to save network resources, but actual information may be retrieved on demand. The German armed forces use our CSD technology on various missions.

Our **ABUL system** provides **automated image exploitation for unmanned aerial vehicles** and has many features to

lighten the operators' workload. This system can feed in video streams from many drone types, stabilize them live, show them in a freely configurable representation, and store them in a database. Features include the merger of images into a georeferenced image mosaic, change detection, and tracking of marked objects even when they are temporarily obscured, stereo images and super resolution.

We commenced the development of the **Digital Map Table** to bring the many benefits of digital information flows to strategic and tactical operations centers. It is compatible with all relevant data sources and is tailored to the needs of command staff and operation control centers. The Bundeswehr Command and Staff College, among others, puts it to good use. We have continued to improve the Digital Map Table, adding features and interaction techniques in many projects since. Command and field staff can work not only with conventional devices such as smartphones, tablets and the large physical Digital Map Table, but also in virtual space. The participants can see each other with VR headsets and a 3D representation of the scenario and can interact quite naturally despite being widely separated in reality.

IDEAS AND SUCCESS STORIES

2010–

IOSB: A UNIQUE SPECTRUM OF SCIENTIFIC EXPERTISE

Developing new types of visual sensor systems; utilizing and connecting sensors in an optimal way; processing and evaluating the resulting data streams; helping people, on this basis, to make sound decisions; enhancing processes and controlling autonomous systems intelligently: this fully integrated process and value chain draws on the three core areas of competence enshrined in our name – the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB.
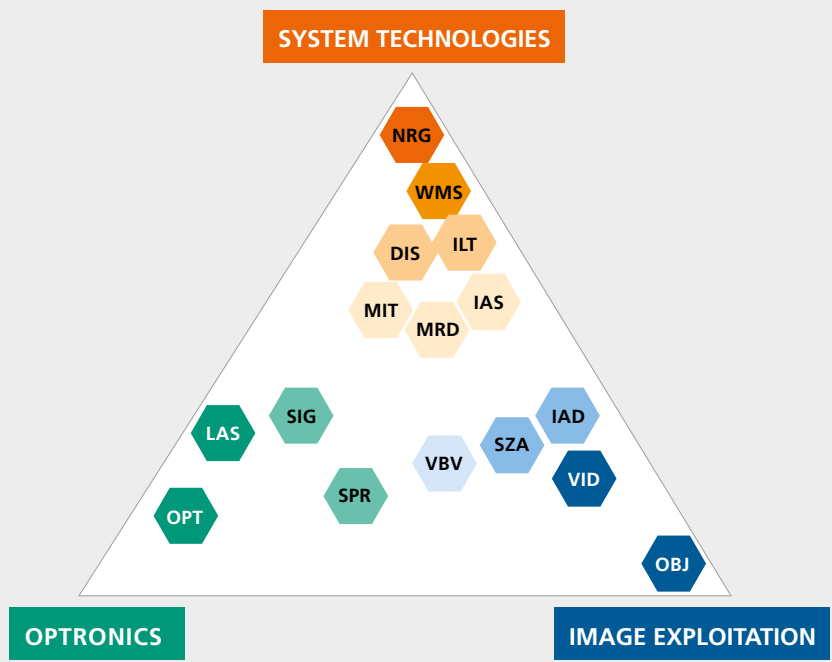
Our institute is Europe's largest research establishment in the field of image capture, processing and analysis. Our activities focus on a wide spectrum of areas, from the physical principles of signal generation to the algorithmic extraction of valuable information from sensor data. We also have wide-ranging expertise in systems engineering, which means we always have an eye for the full picture. In other words, we not only develop algorithms and individual components; we also build complete, ready-to-use systems that utilize sensor data to support people, automate processes and open doors to new forms of human-machine interaction. In everything we do, we implement the highest standards in terms of interoperability, IT security and data protection/privacy.

The institute's Karlsruhe and Ettlingen sites both cooperate closely with the Karlsruhe Institute of Technology (KIT), where Fraunhofer IOSB director Prof. Jürgen Beyerer heads the Vision and Fusion Laboratory at the Institute for Anthropomatics and Robotics (Department of Informatics), and Prof. Marc Eichhorn, director of the Photonics and Optronic Systems division at Fraunhofer IOSB, holds the Chair in Optronics at the Institute of Systems Optimization (Department of Electrical Engineering and Information Technology). In addition, many Fraunhofer IOSB researchers are lecturers at KIT and Karlsruhe University of Applied Sciences. By the same token, professors from these institutions are trustees of Fraunhofer IOSB or act as consultants to the institute. The institute's other sites in Ilmenau, Lemgo and Görlitz maintain similarly close ties to local universities, resulting in a Chair in Energy Usage Optimization at the Ilmenau University of Technology, a newly created, still-to-be-filled Chair in Cognitive Automation at Bielefeld University, and various other chairs at the universities of applied sciences of Schmalkalden, Zittau/Görlitz and Ostwestfalen-Lippe.

The institute's core areas of competence are spread among **15 scientific departments**. In addition, a further research group links the institute with the university chair occupied by our institute director. The competence triangle of expertise represented in the graphic to the right shows how individual departments are positioned in relation to the three core competences specified in the institute's name.

CORE COMPETENCES AND STRUCTURE

OPTRONICS

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

LAS   Laser Technology
OPT   Optronics
SIG   Signatorics
SPR   Visual Inspection Systems

SYSTEM TECHNOLOGIES

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

DIS   Digital Infrastructure
IAS   Interoperability and Assistance Systems
ILT   Information Management and Production Control
MIT   Machine Intelligence
MRD   Systems for Measurement, Control and Diagnosis
NRG   Energy Systems
WMS   Water and Mobile Systems

IMAGE EXPLOITATION

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

IAD   Interactive Analysis and Diagnosis
OBJ   Object Recognition
SZA   Scene Analysis
VID   Video Exploitation Systems
VBV   Variable Image Acquisition and Processing research group

SYSTEM TECHNOLOGIES

NRG
WMS
DIS   ILT
MIT   IAS
MRD

SIG   IAD
LAS   VBV   SZA
OPT   SPR   VID
OBJ

OPTRONICS   IMAGE EXPLOITATION

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

17

EXPERTISE IN APPLICATIONS AND MARKET-ORIENTED SOLUTIONS

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

As an institute committed to applications-oriented research, we source roughly one-third of our budget from projects for clients from a range of industries, including both private-sector companies and public-sector bodies such as municipalities or environmental and security agencies. A further one-third comes from publicly funded research projects, where we often cooperate with companies and other application partners as well as research organizations. Such collaboration keeps us in continuous dialogue with a broad range of partners and helps us constantly deepen our applied know-how in the most diverse of domains. This, in turn, puts us in a prime position to pursue highly topical, game-changing scientific research and technological innovation, meaning that we are able to make optimal use of the final one-third of our financing, which is base funding.

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

In 2019, we reorganized our business units in order to equip them to tackle the challenges of the future. Our five business units are now:

Artificial Intelligence and Autonomous Systems

Automation and Digitalization

Defense

Energy, Environmental and Security Systems

Inspection and Optronic Systems

BUSINESS EXPENSES

How much money did we spend?

70
60
50
40
30
20
10

'15 '16 '17 '18 '19*
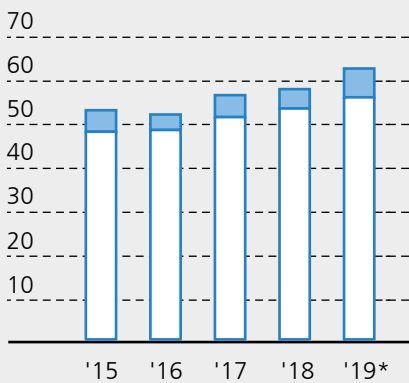
☐ Investment

☐ Research expenditure

FUNDING

Where did the money come from (in 2019)? *

Industrial sector
37%

Basic funding
28%

Others
4%

Public sector
31%
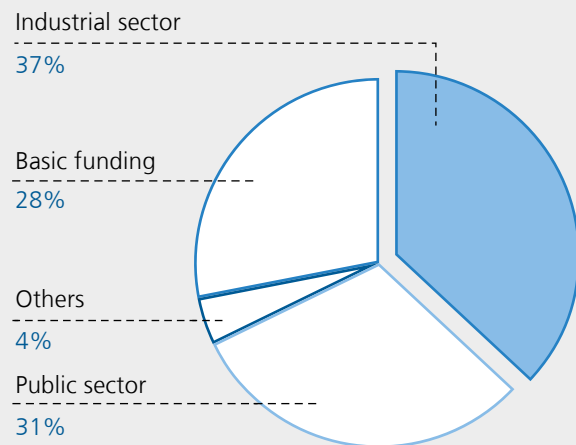
STAFF

How many persons worked at Fraunhofer IOSB? **

'19
'18
'17
'16
'15

100 200 300 400 500 600 700
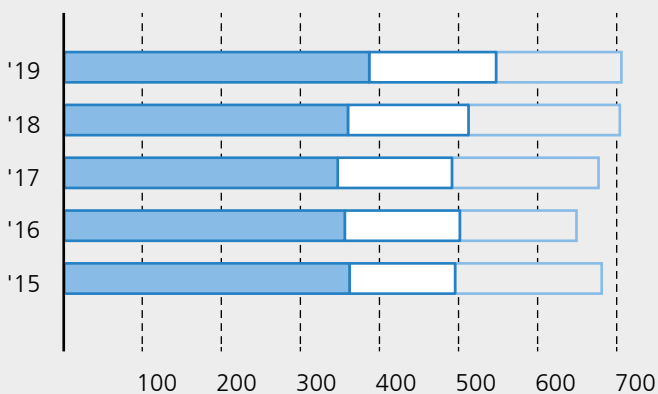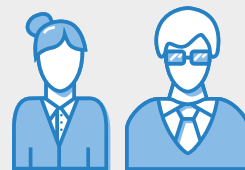
☐ Scientists and engineers

☐ Other regular employees

☐ Research assistants, student assistants and interns

Preliminary figures as of February 2020

*** Headcount reporting date: March 31*

HOW TO WORK WITH US

Our range of solutions and services comprises a broad portfolio of subjects and expertise. Moreover, it also covers the entire spectrum of development stages – from basic research to the finished product; or, in other words, from TRL 1 through to TRL 9. On behalf of our clients from the private and public sectors, we provide or perform the following:

Studies: You have a question? You want to know, for example, what is technologically feasible in a certain area? We provide you with a well-formulated written answer.

Consulting: You want to build your company or develop a project? We lend you our know-how and develop concepts, plan facilities, assist with procurement and facilitate other concrete steps.

Evaluation and certification: You have a system you wish to assess in terms of, for example, its compliance with security or interoperability regulations? With respect to certain standards, we can perform the required testing and issue certification.

Demonstrators: You want to illustrate the potential of a specific technology using sample 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, if required, deliver fully functional components and systems.

Training courses: You want to train yourself or your colleagues in specific topics that lie within our field of expertise? We create training courses and events with a high practical relevance.

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

In addition to direct contracting, we also make our expertise available via numerous collaborations and expert networks, either with a thematic or a regional focus, in partnership with other research organizations or companies (see facing page).

SELECTED STRATEGIC COLLABORATIONS, EXPERT NETWORKS AND PLATFORMS WE ARE PARTICIPATING IN

ROBDEKON

KASTEL

PROFILREGION MOBILITÄTSSYSTEME KARLSRUHE

Lernende Systeme — DIE PLATTFORM FÜR KÜNSTLICHE INTELLIGENZ

Lemgo Digital

Open District Hub — Für die Zukunft der Energiewende

it's owl

OGC Member

BAUHAUS. MOBILITY LAB

Smart Factory OWL

Karlsruher Forschungsfabrik®

Innovationsallianz TechnologieRegion Karlsruhe

IIC MEMBER — industrial internet CONSORTIUM — www.iiconsortium.org

INTERNATIONAL DATA SPACES ASSOCIATION

PLATTFORM INDUSTRIE 4.0

Mittelstand-Digital

ALLIANZ Industrie 4.0 BADEN-WÜRTTEMBERG

Smart Electronic Factory

ONCITE

<AutomationML/> The Glue for Seamless Automation Engineering

Photonics BW Innovation Cluster Optical Technologies

ORGANIZATION CHART

KARLSRUHE

ETTLINGEN

Photonics and Optronic Systems Division

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

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

Head of Institute
**Prof. Dr.-Ing. habil.
Jürgen Beyerer**

Deputies
**Prof. Dr. rer. nat. habil.
Marc Eichhorn
Dr. rer. nat. Jürgen Geisler
Dr.-Ing. Olaf Sauer**

SPR | Visual Inspection Systems

Prof. Dr.-Ing. Thomas Längle

OPT | Optronics

Dr. rer. nat. Helge Bürsing

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

SIG | Signatorics

Dr. rer. nat. Karin Stein

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

LAS | Laser Technology

Dr. Christelle Kieleck

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

OBJ | Object Recognition

Dr. rer. nat. Michael Arens

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

SZA | Scene Analysis

Dr.-Ing. Karsten Schulz

Core Competences

OPTRONICS

SYSTEM TECHNOLOGIES

IMAGE EXPLOITATION

VID | Video Exploitation Systems

Dr.-Ing. Markus Müller

**VBV | Variable Image Acquisition and
Processing (Research Group)**
N. N.

ILMENAU / GÖRLITZ   LEMGO

Advanced System Technology
branch Fraunhofer IOSB-AST

Industrial Automation
branch Fraunhofer IOSB-INA

Prof. Dr.-Ing. habil. Thomas Rauschenbach
Director Ilmenau

Prof. Dr.-Ing. Jürgen Jasperneite
Director Lemgo

BOARD OF DIRECTORS

WMS | Water and Mobile Systems

Prof. Dr.-Ing. habil. Thomas Rauschenbach

DIS | Digital Infrastructure

Prof. Dr.-Ing. Jürgen Jasperneite

NRG | Energy Systems
Prof. Dr.-Ing. Peter Bretschneider
Deputy director Ilmenau

MIT | Machine Intelligence

Dr. rer. nat. Oliver Niehörster

ADMINISTRATION

STAFF DEPARTMENT

BEIJING

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

Head of Staff department
Dr. rer. nat. Jürgen Geisler

Representative Office China
Dipl.-Ing. Hong Mu

IT-Security
Dipl.-Inform. Birger Krägelin

Press and Communications
Dipl.-Phys. Ulrich Pontes

**Strategy and
Innovation Management**
Dr. rer. nat. Frank Lorenz

OPENING OF ROBDEKON

New research infrastructure ROBDEKON, a new competence center to investigate the use of robots for decontaminating hostile environments, was inaugurated on June 25, 2019. This new facility was funded by the Federal Ministry of Education and Research (BMBF) and will be coordinated by Fraunhofer IOSB. The opening ceremony was held in the new research building on the Fraunhofer IOSB site in Karlsruhe and was attended by representatives from government, industry, science and research, and the press. Project partners showcased some of the latest developments in this field. These included the IOSB.BoB autonomous excavator, the humanoid robot ARMAR-6 (Karlsruhe Institute of Technology), a robot for sorting garbage on a conveyor belt (FZI Research Center for Information Technology) and a hybrid walking/driving rover (DFKI Robotics Innovation Center).

AWARD-WINNING AI EXPERTISE

One hundred locations for Industrie 4.0 In an announcement on December 3, 2019, Allianz Industrie 4.0 named Fraunhofer IOSB as one of the top 100 locations for Industrie 4.0 in Baden-Württemberg. It was the second time since 2015 that Fraunhofer IOSB has received the award. In 2019, the award focused on the use of artificial intelligence in manufacturing, with the jury of experts rewarding companies and institutions that demonstrate a high degree of innovation and market relevance.

The award confirms that Fraunhofer IOSB is on the right track, e.g. with its involvement in the Karlsruhe Research Factory. It will be opened in 2020 by the Fraunhofer-Gesellschaft in partnership with the Karlsruhe Institute of Technology. This new facility will investigate AI applications for manufacturing in a realistic setting and thereby accelerate the transfer to industry of, in particular, processes that are still not completely understood.

Fraunhofer IOSB has made further telling contributions to this field, including basic research for the Fraunhofer lighthouse project "ML4P – Machine Learning for Production" and concrete development contracts for industry. The institute has expertise in all the major aspects of AI and machine learning in production. Here, the key challenge is to extract the relevant data from machine-control software and sensors, then to select the right machine-learning methods to generate models from that data (the "learning" process), and, finally, to create a suitable IT system architecture that enables fast processing of the data and models (edge computing). Fraunhofer IOSB also develops methods and guides describing how typical ML use cases can be implemented systematically and as easily as possible in manufacturing.

FRAUNHOFER IOSB-INA CELEBRATES 10TH ANNIVERSARY

Anniversary and relocation to new premises Fraunhofer IOSB-INA celebrated its tenth anniversary on October 1, 2019. Back in 2009, Professor Jürgen Jasperneite, now a member of the board of directors of Fraunhofer IOSB, started up in Lemgo with three young and dedicated scientists, all provisionally accommodated in office containers. Their goal? To help shape the future of industrial communications. The inaugural project? To develop a chip for high-performance real-time communications. Today, a 75-strong team pursues top-level applied research under the motto "Empowering our partners for the digital age." The focus is on providing knowledge and technology for digital transformation in manufacturing companies and municipalities.

Over the past ten years, Fraunhofer IOSB-INA has become a renowned institution in the technology region of Ostwestfalen-Lippe. An early infrastructure milestone was the construction of the Centrum Industrial IT in 2010. This was Germany's first science-to-business center in the field of industrial automation and home to IOSB-INA until 2019. In 2012, with financial assistance from the State of North Rhine-Westphalia, IOSB-INA expanded to become a Fraunhofer application center – the first to be established in cooperation with a university of applied sciences. Since then, Fraunhofer IOSB-INA has been involved in designing the BMBF cluster of excellence "Intelligent Technical Systems Ostwestfalen-Lippe (it's OWL)". It began broadening its research to include cognitive processes based on connected embedded systems as well as intuitive interaction technologies for intelligent technical systems. Before long, artificial intelligence and big data became part of the portfolio. A high performance computing cluster was established in 2016. That same year saw the opening of SmartFactoryOWL, a research and demonstration facility for Industrie 4.0, run in partnership with the Technische Hochschule Ostwestfalen-Lippe. Today, SmartFactoryOWL is a major attraction, drawing several thousand visitors a year. It is directly connected to the new institute building, to which IOSB-INA relocated at the beginning of 2020.

SMART VIDEO SURVEILLANCE

Security and data protection in public spaces December 3, 2018, saw the launch in Mannheim of a project that is unique in Europe: the use of intelligent, algorithm-based video surveillance in public spaces in order to combat street crime. The system aims to automatically recognize certain behavioral patterns indicative of criminal activity – such as kicking or punching – and alerts police officers in the control and operations center. The officers can then assess the situation and decide whether it is serious enough to warrant sending a patrol to the scene.

The system, which utilizes machine learning, was developed by Fraunhofer IOSB and is currently in trial operation. At present, the images are also evaluated by police officers. All recordings are deleted after 72 hours. To enable the AI-based system to recognize situations of interest to the police, it must be fed with training data in the form of images from similar situations. Since data protection legislation prohibits the collection of such recordings in the public domain, the project has a genuine pilot character. The city of Mannheim and the State of Baden-Württemberg are investing 1.6 million euros in the project over a period of five years. Around one-third of this sum will go to Fraunhofer IOSB.

Smart video surveillance marks a step towards greater data protection and privacy. Instead of identifying persons, the system focuses exclusively on specific movement patterns. In the future, when the system is able to reliably identify critical situations, it will be possible to pixelate the images. Only when the system judges that a situation requires closer human scrutiny will sharp images be shown.

TWO SPIN-OFFS

Ampeers Energy and Gixel The year 2019 saw the launch of two spin-offs from Fraunhofer IOSB. Munich-based **Ampeers Energy GmbH** is seeking to capitalize on the transition to a sustainable – and decentralized – energy supply. The spin-off provides a cloud-based software ecosystem that helps exploit new business opportunities and protect the environment. Its portfolio of solutions comprises software to manage energy supply to districts, to manage the supply of electricity to tenants, and to manage the controlled recharging of commercial fleets of electric vehicles. All three solutions are based on an energy management platform developed at Fraunhofer IOSB-AST, which integrates artificial intelligence features.

AI-based processes are also part of the portfolio at the Karlsruhe-based spin-off **Gixel GmbH** – here, in the field of machine vision. The company founders are seeking to leverage the expertise they acquired at Fraunhofer IOSB and the Karlsruhe Institute of Technology: on the basis of a quick and simple teach-in process, they aim to make image analysis systems much more user-friendly, whether for quality control or automating the processing of lab results. They have also developed an especially fast 3D optical sensor based on a new type of confocal chromatic measuring principle.

IOSB-AST IN NEW PREMISES

New institute building in Ilmenau Relocation began in the fall of 2019. Little by little, the about 100 employees of Fraunhofer IOSB-AST moved to the offices and labs of the newly erected building. It is located in the industrial park Am Vogelherd within sight of the old building. The new building is a joint project of Fraunhofer IOSB-AST and the Electronic Measurements and Signal Processing department of the Fraunhofer Institute for Integrated Circuits IIS.

It provides 3,400 square meters of office, lab and training space for the two research bodies and can accommodate up to 212 employees. The construction costs of around 25 million euros were funded to 40 percent by the European Regional Development Fund (ERDF), by the State of Thuringia (30 percent) and by the German federal government (30 percent).

MOBILITY OF THE FUTURE

Profile Region Mobility Systems Karlsruhe and Test Field Autonomous Driving Baden-Württemberg With the growing demand for mobility, an increase in freight transportation and, above all, the question of sustainability, the challenges facing the transportation sector are becoming ever more complex. In response, the State of Baden-Württemberg sponsors the Profile Region Mobility Systems Karlsruhe in which Fraunhofer IOSB cooperates with other Karlsruhe-based research institutes and universities. It provides companies, planers and political decision-makers with a single gateway to the combined mobility expertise of all these institutions. This covers a wide spectrum, ranging from (fully) automated vehicles and innovative drive systems to the societal impact. The two-year core phase started on May 10, 2019, with funding of over nine million euros available for research projects.

Opened in 2018, the Test Field Autonomous Driving Baden-Württemberg works hand in hand with the Profile Region Mobility Systems Karlsruhe. It is a real laboratory with the infrastructure to test, in real road traffic, the technology and services required for automated and networked driving. It uses a variety of traffic areas, high-precision 3D maps, and sensors to capture traffic information and influencing factors.

Fraunhofer IOSB contributes its automotive expertise to both consortia: situation recognition and maneuver planning for automated and networked driving, Car2X communication, emissions reduction, interior monitoring, as well as generation of training data for machine learning. With its privacy-by-design expertise, Fraunhofer IOSB also develops solutions to protect data and maintain privacy despite digitalization and the increased sensor-based capturing of traffic information.

FUTURE SECURITY 2019

Forum for defense and security research Future Security 2019, the conference of the Fraunhofer Group for Defense and Security VVS, was held in the Fraunhofer-Forum in Berlin from March 14–15. Following a break of three years, it returned with the slogan "Disruptive technologies in defense and security" and a new format. Instead of the traditional scientific congress there was a compact meet-and-discuss forum from midday to midday – free of charge, focused on specific topics with a program of invited speakers only.

The new concept was a hit. Some 170 participants from science, research, government, public administration and industry heard keynote addresses from high-ranking officials from the German federal ministries of defense and the interior, and from the European Commission. Topics included the strategic challenges involved in major arms projects, technological innovation management, the breathtaking pace of developments in cyberspace, and the planned European Defence Fund (EDF). There to explain at first hand the rationale behind the EDF and its current status was Sylvia Kainz-Huber, head of unit at the Directorate General GROW in Brussels (see photo).

Expert sessions focused on the technology fields of high-energy lasers, artificial intelligence and autonomous systems, as well as cyber defense and security, with presentations from research, development, and from operational divisions in government agencies. Between sessions, conference-goers visited the accompanying exhibition, which included exhibits from institutes in the VVS Group. Future Security was planned and organized by Fraunhofer IOSB. The next Future Security will be held in early 2021.

HARMONIZING IIOT ARCHITECTURES

Fraunhofer IOSB builds bridges with Smart Factory Web
On the international level, there are currently a number of vendor-neutral initiatives that aim to develop the Industrial Internet on the basis of open standards and trustworthy, interoperable architectures. Three of the most important are the Industrial Internet Consortium (IIC), Plattform Industrie 4.0 (PI4.0) and the International Data Spaces Association (IDSA), which is committed to a trustworthy architecture in the data economy. As a longstanding contributor to the development of an interoperable Industrial Internet of Things (IIoT), Fraunhofer IOSB is closely linked to all three initiatives – and is now playing a leading role in building bridges between the different reference architectures and also in building and leading an industrial community on behalf of IDSA.

Smart Factory Web (SFW), an online marketplace for production capacity developed by Fraunhofer IOSB (cf. p. 43), has been a recognized IIC testbed since 2016. In September 2018, when IIC and IDSA signed a memorandum of understanding, SFW was designated as a joint testbed. This was followed soon afterwards by the launch of SYNERGY, a project that gave concrete form to this collaboration by integrating components of the International Data Spaces into SFW. This will enable more secure and trustworthy connections between the participants of the marketplace. At the same time, it marks a first step towards technological interconnectivity and convergence between the three initiatives named above.

On April 1, 2019, at the Hannover Messe, IIC and PI4.0 likewise announced closer cooperation and nominated SFW as a potential joint testbed. The photo above shows the heads of Plattform Industrie 4.0 and the IIC, Henning Banthien (left) and Richard Soley resp., pictured in front of the SFW exhibit, provided by Fraunhofer IOSB and the SFW participants, in Hall 8 of the Hannover Messe.

SMART CITY LIVING LAB

Launch of LEMGO DIGITAL How can the Internet of Things (IoT) facilitate urban living? Fraunhofer IOSB-INA has inaugurated LEMGO DIGITAL to answer this question for concrete application projects. The project was officially launched in May 2018 in the presence of Professor Andreas Pinkwart, North Rhine-Westphalia State Minister for Business and Digital Affairs. LEMGO DIGITAL is an open platform for developing and testing innovations for digital transformation in small and medium-sized towns. In partnership with the University of Applied Sciences and Arts, Ostwestfalen-Lippe as well as research institutions and partners from industry, it seeks to create innovative solutions to everyday urban problems in the areas of mobility, the environment, commerce and energy supply.

Many smart city projects focus on large cities. LEMGO DIGITAL, however, has been designed to answer the needs of medium-size towns – with between 20,000 and 100,000 inhabitants – of which there are over 600 in Germany. Moreover, unlike other projects, LEMGO DIGITAL has actively encouraged the participation of both citizens and IoT startups from a very early stage onward. The project has turned the town of Lemgo into a living play-along labor – with the scientific and business communities working hand in hand with the general public to shape technological innovation.

So far, the project has resulted in the creation of an open-access Wi-Fi network throughout the town and a sensor infrastructure to monitor the traffic situation. Real-time information on public transport facilitates travel. In addition, work is progressing on a smart parking-management app. Finally, the mayor has been presented with a dashboard (web site) that displays live information on traffic, the weather, the number of visitors to the town etc.

POOLING EXPERTISE

The institutes of the Fraunhofer-Gesellschaft cooperate with each other in different constellations, leveraging synergies and securing Fraunhofer's leading position in the development of system solutions and the implementation of holistic innovations. Fraunhofer IOSB is a member of two Fraunhofer Groups: the Fraunhofer ICT group and the Fraunhofer Group for Defense and Security (see following pages). It is also active in 13 Fraunhofer Alliances and participates in two Clusters of Excellence as well as five Fraunhofer Lighthouse Projects.

Fraunhofer Information and Communication Technology Group

The Fraunhofer ICT Group is the largest provider of applied research in the field of information and communication technologies in Europe. It marshals key expertise for business and society to utilize in exploiting opportunities and meeting the challenges that result from the comprehensive digitalization of virtually all aspects of today's new world.

The Fraunhofer ICT Group covers a broad spectrum of technological fields through its member institutes, from the basics to practical solutions. It offers assistance to national and international IT providers and IT users alike, particularly SMEs. In addition, it defines and works on the predominant topics crucial for the future of business and society through interdisciplinary initiatives at the highest conceptual level.

Technology fields: Numerical software & simulation, usability & human-computer interaction, reliable cyber physical systems, IT security & safety, digital networks & the Internet, computer graphics & media technology, image acquisition & evaluation, big data management & analytics, automation technology & engineering.

Cluster of Excellence Cognitive Internet Technologies

The cluster explores cognitive technologies for the industrial Internet and develops key technologies along the value-added chain – from sensors to intelligent learning processes in data processing to the cloud.

Cluster of Excellence Integrated Energy Systems

This research cluster addresses the central technical and economic challenges of the next phase of the global energy transition, pursuing thie vision of transforming Fraunhofer into the lead research institution for applied energy research.

Fraunhofer Lighthouse Projects

ML4P
Machine Learning for Production
(This project is coordinated by Fraunhofer IOSB)

COGNAC
Cognitive Agriculture

MED²ICIN
Digital patient model as a basis for personalised and cost-optimized treatment

QUILT
Quantum Methods for Advanced Imaging Solutions

VBM4MZ
Combustion Engines for Tomorrow's Mobility
(including cognitive combustion engines)

Fraunhofer AutoMOBILE Production Alliance

Powertrain and running gear, electric mobility, planning, control and logistics, car body, vehicle assembly, vehicle interior

Fraunhofer Big Data and Artificial Intelligence Alliance

Logistics and mobility, production / Industrie 4.0, life sciences and health care, data security, energy and environment, business and finances

Fraunhofer Energy Alliance

Renewable energy, energy in digital context, energy systems, energy storage, energy efficiency, energy in urban context

Fraunhofer Food Chain Management Alliance

Food chemistry, food packaging technology, logistics, microsystems technology

Fraunhofer Space Alliance

Communication and navigation, materials and processes, energy and electronics, surfaces and optical systems, protection technology and reliability, sensor systems and analysis

Fraunhofer Traffic and Transportation Alliance

Comfort and design concepts, safety systems, resource- and energy-efficient transportation, logistical structures and processes, innovative mobility and traffic systems, smart and resilient transportation infrastructure

Fraunhofer Vision Alliance

Industrial image processing, 3D surveying, thermography, X-ray technology, surface inspection, medical engineering, safety engineering, traffic engineering, terahertz tomography

Fraunhofer Water Systems Alliance (SysWasser)

Urban/periurban water management systems, processes and systems for the supply with drinking and service water, wastewater treatment processes and systems, integrated water resource management (IWRM), analysis and evaluation of water-economic systems

Institutes working in related subject areas cooperate in **Fraunhofer Groups** and foster a joint presence on the R&D market. They help to define the Fraunhofer-Gesellschaft's business policy and act to implement its organizational and funding principles. The groups' chairpersons are part of the Presidential Council of the Fraunhofer-Gesellschaft.

The **Fraunhofer Alliances** facilitate customer access to the services and research results of the Fraunhofer-Gesellschaft. Common points of contact for groups of institutes active in related fields provide expert advice on complex issues and coordinate the development of appropriate solutions.

As a sort of "virtual institute" spread over multiple locations, the **Fraunhofer Clusters of Excellence** promote cooperative development of system-relevant topics through an inter-institute research structure. Their purpose is not simply to implement specific, short-term projects but rather to follow a roadmap for the long-term devel-opment of a complex technological trend.

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

FRAUNHOFER GROUP FOR DEFENSE AND SECURITY VVS

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

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

The Fraunhofer Group 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 group.

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

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

Group chairman
Prof. Dr.-Ing. habil.
Jürgen Beyerer,
Fraunhofer IOSB

Group deputy chairman
Prof. Dr. rer. nat
Peter Martini,
Fraunhofer FKIE

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servlet/is/100261

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

VVS

**for a life
of freedom**

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
- Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE
  Command, Control and Reconnaissance
- Fraunhofer Institute for Applied Solid State Physics IAF
  Sensors for Safety, Security and Reconnaissance
- Fraunhofer Institute for Chemical Technology ICT
  Security, Safety and Energetic Materials Technology

- Fraunhofer Institute for Technological Trend Analysis INT
  Planning Support for State and Industry
- Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB
  From Networked Sensor Data to Decision
- Fraunhofer Institute for Experimental Software Engineering IESE
  Software and Systems Engineering
- Fraunhofer Institute for Integrated Circuits IIS
  Communication, Positioning Technologies and X-Ray for Safety and Security Applications
- Fraunhofer Institute for Structural Durability and Systems Reliability LBF
  Secure Processes for secure Structures

FRAUNHOFER-GESELLSCHAFT

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft maintains 74 institutes and research units. The majority of the more than 28,000 staff are qualified scientists and engineers, who work with an annual research budget of 2.8 billion euros. Of this sum, 2.3 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

BUSINESS UNITS

Artificial Intelligence and Autonomous Systems

36 – 39

Automation and Digitalization

40 – 43

Defense

44 – 47

Energy, Environmental and Security Systems

48 – 51

Inspection and Optronic Systems

52 – 55

ARTIFICIAL INTELLIGENCE AND AUTONOMOUS SYSTEMS

From basic questions to embodied AI

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

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

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

DEPARTMENTS INVOLVED

- DIS
- IAD
- IAS
- ILT
- MIT
- MRD
- NRG
- VID
- WMS

SCOPE

- Knowledge representation
- Explainable AI
- Data analysis with AI
- AI engineering
- Perception
- Autonomous mobile systems
- Assistance systems
- Social Intelligence

SELECTED TECHNOLOGIES

- Deep learning
- Bayesian networks
- Evolutionary algorithms
- Grey box modeling
- SLAM
- Body-pose estimation
- Reinforcement Learning
- Cooperative Autonomous Systems
- Semantic knowledge representation

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"AI WILL NEVER REPLACE A HUMAN BEING"

The very specific strengths of artificial intelligence can help improve decision-making

Everyone, it seems, is talking about artificial intelligence. Yet people still have reservations, particularly regarding data protection and the perceived threat to jobs. What's the significance of AI for Fraunhofer IOSB?

Rauschenbach: Well, firstly, I should say that artificial intelligence is not all that new. We've been using AI since the 1990s. It's what power companies use to predict the consumption of tens of thousands of customers, or automakers to ensure quality in vehicle production. But AI doesn't replace an actual person in these or any other areas. When we use AI in our projects, we use it to provide support with human decision-making.

In which areas is AI already better than humans?

Rauschenbach: The human brain is extremely good at pattern recognition. For example, we have no problem distinguishing a cup of coffee from a glass of water. However, the picture changes when it comes to recognizing patterns in extremely large datasets, also known as big data. Artificial intelligence is far better at this than humans. At Fraunhofer IOSB, we use pattern recognition to analyze so-called PMU data (*see overleaf: Enhancing grid stability with AI*). Here, every single sensor generates 150 datasets every second. The aim here is to recognize malfunctions in the power grid before they even occur. This is the kind of application for which we can really exploit the strengths of AI. Other areas currently being investigated by our researchers include predictive maintenance for Industrie 4.0, automated detection of physical assaults, and object recognition for autonomous underwater vehicles. In other words, all of these involve the use of AI-based systems to assist with the human decision-making process.

Where is research still needed? And what are the drawbacks of AI compared to conventional statistical analysis?

Rauschenbach: One of the big challenges we face with a number of deep-learning processes is that it is impossible to explain with absolute certainty just how they arrive at the results they do. By contrast, we understand very well how a statistically based predictive model, such as the similar days method, generates its results. A lot of AI is a bit like a black box: if the result isn't quite right, it's very difficult to say what's gone wrong. That's why "Explainable AI" (XAI) is such a big research topic right now. And it's one we're looking at very closely here, too.

Prof. Thomas Rauschenbach is head of the WMS department and director of the Advanced System Technologies branch AST of Fraunhofer IOSB.

AKIT: Retrofitting vehicles for autonomous recovery operations

AKIT is a joint project funded by the German Federal Ministry of Education and Research. Its purpose was to develop a retrofit kit with which standard heavy-duty vehicles such as excavators and tractors can be rapidly converted into autonomous recovery vehicles for use in major incidents and disaster areas.

The kit comprises sensors along with various other components. It enables functions such as autonomous navigation in rough terrain, 3D-based assisted object manipulation, and situation-specific connectivity. Vehicles retrofitted with this kit can help emergency teams to rapidly deal with dangerous situations, such as danger of collapse, explosion, or chemical or radiological contamination, without putting rescue workers at risk. The development of a retrofit kit relieves the emergency services of the need to have special equipment on standby. Rather, in the event of a major incident, normal working vehicles can be quickly converted for use in recovery operations.

Together with partners, Fraunhofer IOSB has developed and successfully demonstrated a recovery package comprising a highly automated recovery vehicle, support shuttle and communications systems (see image). With further research now scheduled, the aim is to take these project findings to industrial maturity.

Enhancing grid stability with AI

The growing use of renewable energy has placed electricity grids under increased strain, especially at times of fluctuating loads. Conventional measurement systems no longer suffice to detect critical network situations. Increasingly, therefore, these are being supplemented by ultraprecise, synchronous phasor measurement units (PMUs). PMUs enable real-time monitoring of key grid parameters such as frequency, voltage and phase angle.

Samples are captured as frequently as 50 times per second. This generates substantial volumes of data – several gigabytes a day – which has to be recorded and processed as efficiently as possible. Fraunhofer IOSB-AST has developed a method of data compression that reduces the storage capacity required to archive this data by as much as 80 percent. Moreover, this compression also speeds up subsequent data analysis.

AI-based processes are then used to provide automatic analysis of the PMU readings, thereby enabling real-time detection of any deviations from normal grid operation (anomaly detection) as well as certain malfunctions (disturbance classification).

🌐 *a-kit.de*

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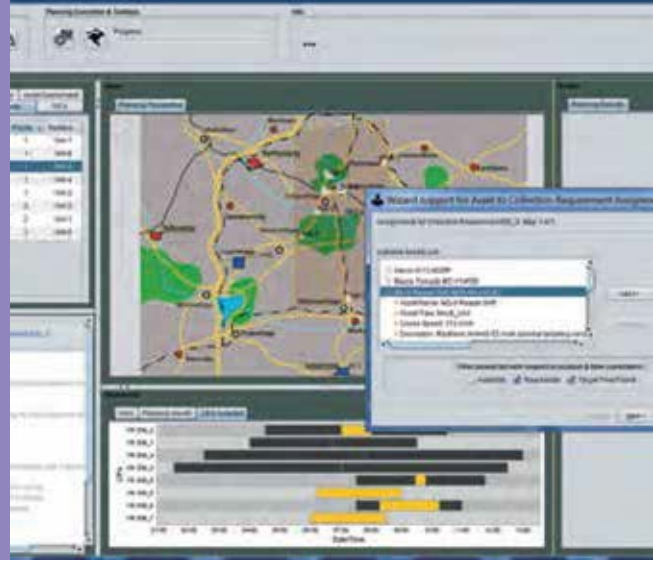
Enhancing public security with AI

Despite the many changes that globalization, digital transformation and permanent connectivity have brought to our lives, "analog" crimes are still being committed on a "local" level every day. Yet modern technology can help guard us against such criminal acts as well as provide better protection of our privacy. In so doing, it can also increase public confidence in the work done by the law-enforcement agencies and in government policymaking.

In a collaborative project with the city of Mannheim, the metropolitan police department and Baden-Württemberg's State Ministry of the Interior, Fraunhofer IOSB is demonstrating how smart video surveillance can help prevent crime. The system software analyses live video from a network of cameras with the aim of identifying, in real time, acts of physical violence – for example, kicking or punching. Whenever the system recognizes an assault, it flags it so that the monitoring team in the control room can decide whether the incident is serious enough to warrant some form of intervention, such as sending a beat officer or patrol car to the scene.

In other words, the system merely has an auxiliary role, assisting the police with routine surveillance. Moreover, it also permits the pixelation of normal, harmless scenes, which can only alleviate the fears of those concerned about data protection and privacy.

AI applications for improved intelligence, surveillance and reconnaissance

The success of intelligence, surveillance and reconnaissance (ISR) operations relies on the timely provision of accurate, relevant and coherent information generated across a range of increasingly heterogeneous platforms, both manned and unmanned. Proper evaluation of this data is essential for a high level of situational awareness. AI-based systems have a key role to play here. Examples of such AI support include assisted image exploitation and support for ISR management. To optimize the assignment of ISR assets to intelligence and surveillance requirements, Fraunhofer IOSB has developed an ISR Manager application (see image).

In many cases, information has to be evaluated and disseminated to command structures while a mission is still ongoing. To ensure the most efficient and effective use of resources, mission command must be able to react according to a changing situation on the ground. To meet this need, Fraunhofer IOSB develops systems to assist with dynamic mission planning and the control of heterogeneous groups of mobile systems based on different AI systems. In particular, this involves the use of software agents, genetic algorithms and the behavioral control of individual systems and their groups. It is thereby possible to make inferences about concrete situations on the basis of multi-sensor data such as radar and radio and then, in line with this information, to adjust or reallocate such sensors.

🌐 *iosb.fraunhofer.de/servlet/is/93474*

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AUTOMATION AND DIGITALIZATION

Real-time IT for complex production processes

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

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

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

DEPARTMENTS INVOLVED

- DIS
- IAD
- IAS
- ILT
- MIT
- MRD
- NRG
- SPR

SCOPE

- Industrial Internet of Things (IIoT)
- MES and process-control technology
- Data-driven process optimization
- Industrial communications technology
- Digital twins and administration shells
- Industrial human-machine interaction
- IT security in manufacturing
- Web-based information systems

SELECTED TECHNOLOGIES

- Edge computing
- Cyber-physical systems
- Artificial intelligence and machine learning
- AutomationML and OPC UA
- OPC UA over Time-Sensitive Networking (TSN)
- International Data Spaces (IDS)
- Industrie 4.0 asset administration shell

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"AI EXPERTISE IS NOT ENOUGH ON ITS OWN"

In the future, manufacturing will be self-organizing. To achieve this end, each element of the production network – from sensors to secure cloud interfaces – must harmonize perfectly

Dr. Sauer, everyone's excited about self-organizing manufacturing. What's behind the hype?

Olaf Sauer: For a while now, the trend in manufacturing has been towards ever an increasing product variety and customization, while also cutting delivery times. Conventional production methods – such as the sequencing concept used in the automobile industry, whereby one car after another is processed on the assembly line – soon run into difficulties here. The work that needs to be done at individual stations is simply too varied, with the result that employee and plant utilization decreases. In other words, the idea – which is by no means new – of smart, connected products being able to navigate their way through a modular production environment is more topical than ever.

So, instead of conveyor belts, you have autonomous material flow systems moving each car body individually from one work station to the next?

Sauer: That's the most visible change. But the challenge we face at Fraunhofer IOSB, along with our industry partners, is to optimize the IT systems responsible for production control and automation. First of all, we have to be able to permanently locate products, parts and material flow systems, such as AGVs, and then digitally map these along with other production resources. Essentially, we're talking here about IIoT and real-time visualization. And then all this complex activity has to be able to self-organize in such a way that efficiency is maximized while also guaranteeing a robust response to any unforeseen events such as a fluctuation in orders, supply problems or the unavailability of modules. This requires expertise in AI, especially in areas such as reinforcement learning. But that's not enough on its own. We also need to get the basics

right, which means issues such as simulation, sensor technology, real-time connectivity, interoperability, and suitable OT/IT architectures based on edge and cloud computing. That said, we have a wealth of experience in these fields and have helped define the state of the art in these technologies and will continue to drive them forward in the future.

You mentioned edge and cloud computing. Yet many companies don't want to cede control over their data.

Sauer: That will require trustworthy infrastructures. Besides, isolation is the wrong strategy for manufacturers who want to leverage the advantages of digitalization in production. You need to provide three things simultaneously: performance, data security and connectivity that extends beyond a manufacturer's own location so as to enable effective control of logistic chains. This demands a carefully scaled strategy. That's why we and our partners have been involved for a number of years now in initiatives such as International Data Spaces, German Edge Cloud/ONCITE and Gaia-X. These all address precisely these concerns and also include sophisticated mechanisms to provide maximum data sovereignty and control.

Dr. Olaf Sauer, deputy director of Fraunhofer IOSB, is an expert in automation and coordinates activities at the Automation and Digitalization business unit.

Edge computing platform for PLC virtualization

In recent years, cloud technologies have improved the architecture of Internet-based applications in terms of scalability, optimal utilization of resources and economies of scale in administration. They have also enabled pay-per-use business models, i.e. services that are only executed on demand and share resources. However, for critical applications that require high reliability or sub-millisecond latency for control, information processing/preprocessing must be on-premise and close to the devices. This is where edge computing comes in.

IOSB develops technologies that unlock the potential of edge computing for automation. We have joined forces with German Edge Cloud and cooperate with initiatives such as Plattform Industrie 4.0, International Data Spaces Association (IDSA) and the European cloud Gaia-X to work on the CrossTEP edge computing platform. Its "Virtual PLC" (programmable logic controller) profile focuses on the virtualization of PLCs as edge control services that share computing resources and only run when required.

The main scientific challenges include the consistent engineering of deterministic real-time communication and processing as well as interoperability. The CrossTEP virtual PLC uses the latest Industrie 4.0 standards, e.g. an OPC UA-based Asset Administration Shell (AAS) mapped to Time-Sensitive Networking (TSN), and is validated using our institute's own material sorting system, TableSort (see image).

iosb.fraunhofer.de/servlet/is/99097

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Standard-based modelling of automotive production plants with AutomationML

The Automation Markup Language (AutomationML) is an IEC data format standard that was developed to enable the exchange of production plants' engineering data between heterogenous system engineering tools. Compared to the manual exchange of data between different tools, as is still often the case today, AutomationML reduces the time, costs and possible sources of error. Its standardization and further development are mainly driven by the AutomationML e.V. association, which was born of an industrial consortium that included Daimler, Kuka and ABB.

As another founding member of the association, Fraunhofer IOSB is involved in several of its ongoing working groups, such as the Toolchain and the Asset Administration Shell. In addition, our AutomationML Test Center provides validation and testing services to all the association's members. In a project originally commissioned by BMW but applicable to the whole automotive industry, we are working with Fraunhofer IFF to model an entire automotive production plant with AutomationML.

The result is to serve as a model specification for the plant's central data storage, which will not only support the complete engineering toolchain but is also to be used in the operational phase of a plant. Furthermore, this project will develop a concept for the secure exchange of production plant data between the three major interest groups: component manufacturers, system integrators and plant operators.

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Smart Factory Web – a marketplace for industrial production

The Smart Factory Web aims to set up a web-based platform where factories can offer production capabilities and share resources. This will enable them to improve order fulfillment with greater flexibility than is currently possible with available technology. The Smart Factory Web seeks to provide the technical basis for new business models, especially for small lot sizes, by flexibly assigning production resources across factory locations. This testbed is chiefly designed as a step towards establishing a manufacturing marketplace where one can look for factories with specific capabilities and assets to meet production requirements. Factories with those capabilities can then register to join the marketplace.

This requires up-to-date information about the capabilities and status of assets in the factory. The specifications of the products – availability, quality, price and other parameters – can be used to negotiate in the case of competing offers.

This system hinges on making information about the factories available in a standardized, reliable way. To ensure this, the Smart Factory Web applies international standards such as OPC UA and AutomationML as well as Industrie 4.0 and International Data Spaces (IDS) specifications. Originally started as a testbed run by the Industrial Internet Consortium (IIC) with the Korean research partner KETI, it has since attracted participation by global IT players such as Microsoft and SAP to jointly leverage commercial business cases.

🌐 *smartfactoryweb.de*

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Cybersecurity training lab for industrial manufacturing

The principles and technologies of the Industrial Internet of Things (IIoT) are increasingly finding their way into domains such as manufacturing and critical infrastructures. This trend marks not only a technological shift that enables new and possibly disruptive business models; it also brings heightened security risks due to new vulnerabilities. No longer hidden in shielded, mostly proprietary network environments, IIoT components now come with built-in connectivity options based upon standardized communication networks in order to offer new services such as preventive maintenance.

As a consequence, system architects and engineers in all disciplines need at least basic security and security management know-how and skills; these are essential for drafting and configuring systems and network architectures in such a way that the security level meets the specified security protection goals of the application or organization. Standards for information security management systems such as the ISO/IEC 27000-series and IEC 62443 need to be applied here.

Our cybersecurity training lab for industrial manufacturing, based in Karlsruhe and Lemgo, combines learning modules with a tailored training and education environment. Designed for engineers and computer scientists, it features experimental hardware and software systems that are built from real-world automation components (see image). Like the cybersecurity training lab for energy and water supply in Ilmenau and Görlitz, it lets users see the consequences of cyberattacks and apply and test countermeasures.

🌐 *iosb.fraunhofer.de/servlet/is/72741*

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DEFENSE

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

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

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

DEPARTMENTS INVOLVED

- IAD
- IAS
- LAS
- OBJ
- OPT
- SIG
- SZA
- VID

SCOPE

- Optronic sensor systems
- Signature evaluation and management
- Laser technology
- Analysis of radar and aerial photography
- Object and situation recognition
- Connected command and control
- Connected simulation
- Adaptive optics

SELECTED TECHNOLOGIES

- IR scene simulation
- Modeling of imaging devices
- Nonlinear laser frequency conversion
- Multisensor and hyperspectral sensor technology
- Multimodal human-computer interaction
- THS® (Target Handoff System)
- DigLT (digital map table software)
- Adaptive learning games
- Semantic video analysis
- Coalition Shared Data

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"KEY CAPABILITIES FOR TOMORROW'S BATTLEFIELDS"

Research into future battle tank systems and digitalized military operations

Digitalization is transforming practically every area of life. What impact is it having on defense research?

Michael Arens: The battlefield is changing, though not merely because certain aspects of it have been relocated to the realm of cyberspace. Instead, we're also seeing a shift in the requirements made of armed forces in the real world. With digital technologies available to everyone worldwide, armed forces must ensure they are physically equipped to combat so-called peer adversaries. They need to rapidly process large amounts of intelligence data from different sources so as to build an accurate picture that enables informed operational decisions. For example, they have to be able to operate in GPS-denied environments. At the same time, with weapon systems being transformed by digitalization and automation, the emphasis is now on alliances of highly networked and partly manned/partly unmanned units. All of these considerations play a key role in, for example, the advance discussions on the development of a new European battle tank system. So there's a lot of research and development work to do.

What kind of contribution will Fraunhofer IOSB be able to make here?

Arens: We have expertise in a whole range of technologies that will be crucial for meeting these challenges. For example, we have been developing systems to help evaluate sensor data and other information or fully automate these processes for many years now. This process starts with data acquisition – for example, through the use of planning tools for sensor deployment – and includes the requisite IT systems and architectures for data storage and data sharing between alliance partners. It also involves not only the algorithms used to extract and eval-

uate information but also systems that can present even the most complex situations on a wide variety of device platforms and in a manner appropriate to specific roles, thereby enabling rapid action.

And what about areas beyond the intelligence cycle and the interpretation of reconnaissance data?

Arens: We've got a lot to contribute here as well. In the field of GPS-denied environments, for example, we've been working for some time now on image-based localization and navigation. And we also have the ability to automatically reference other kinds of information within space and time, which means we can fuse this data to form an overall and unified virtual picture. This will be crucial for the future weapon system alliances we referred to earlier, which will comprise manned and unmanned units, and where perhaps one unit will be able to see the target, while another one has to fire at it. When it comes to creating these unmanned units, we have extensive experience with autonomous systems in hostile environments.

Dr. Michael Arens, a computer scientist, is spokesperson of the Defense business unit.
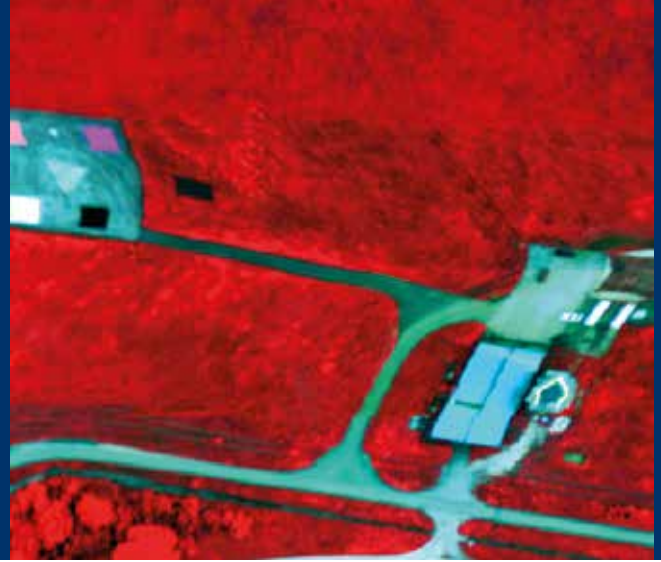
Supporting multinational interoperable ISR

To be able to cope with the challenges and crises of the present age, it is necessary for nations to cooperate in the security and defense domain. The key to success here is to attain information superiority through the timely provision of relevant data. Thanks to advances in sensor and network technology and the growth in storage capacity, it is now possible to generate, store and share large amounts of data in near real time. In order to make effective use of these capabilities in multinational operations, systems and services need to interact in a well-defined, interoperable manner.

Operational processes define which tasks and roles have to be supported, how procedures are executed, which data formats are used and, ultimately, which systems and services need to be connected. In NATO operations, the Joint Intelligence, Surveillance and Reconnaissance (JISR) process and the NATO Intelligence Cycle (see AJP 2.1, 2.7 and AIntP-14; see also graphic above) are fundamental here. Standardized formats, interfaces, and descriptions of services and architectures are essential for the effective provision of technical support. As part of the grant-funded project "JISR contributions to support multinational interoperable reconnaissance coalitions" (JiAV), existing process descriptions are being compared with technical specifications and gaps are identified. The results contribute to the work of multinational bodies that analyze and evolve the standards for data and information dissemination and reporting. In addition, we analyze and develop innovative methods for data distribution such as the utilization of hash tries. We demonstrate our work in prototype solutions that also feature new concepts such as a microservice architecture.

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Real-time hyperspectral data analysis for ISR

In its latest activities in the field of online remote sensing for intelligence, surveillance and reconnaissance (ISR) purposes, Fraunhofer IOSB has developed a method for near real-time detection of camouflage objects, using an integrated, airborne hyperspectral system. The procedure is based on the principle of spectral correlation. For this purpose, a screening algorithm uses unmixed target spectra as well as spectral environment information. The proposed method, visualized in the scene above (including buildings, meadows and test areas with camouflage material), boasts a very high detection rate in combination with a low false-alarm rate. It is robust with respect to lighting variations and the influence of stray radiation from the surroundings. Our comprehensive statistical tests have shown that detection is excellent even for very small objects.

We acquired in-situ data from the technology demonstrator SELSAS-HYM and optimized the method in accordance with the demands and hardware restrictions of the flight platform. The main sensor in this system is a hyperspectral push-broom sensor in the VNIR range, deployed in conjunction with multispectral cameras. The near real-time capabilities were achieved using off-the-shelf hardware. Data processing is twice as fast as the rate of data acquisition thanks to a special update formula for the applied screening algorithm. We were able to meet all the requirements for a future reconnaissance system capable of providing tactical ISR information while the flight system is still in the air, thereby allowing online utilization. We therefore successfully demonstrated the potential of real-time hyperspectral data analysis as a key technology for advanced ISR capabilities.

🌐 *iosb.fraunhofer.de/servlet/is/44300*

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Image interpretation

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Dazzling of optronic sensor systems

Over the past decade, the use of compact, commercially available, high-power continuous wave (CW) "laser pointers" has increased among the general public. There have also been regular reports in the news of such lasers being misused, especially with people aiming them at low-flying aircraft during the hours of darkness. Bright light, such as from a laser pointer, produces dazzle effects that interfere with the pilot's vision, thereby risking disaster.

In order to gain a better understanding of situations where aircraft pilots are dazzled with handheld laser pointers, Fraunhofer IOSB took part in a joint NATO SET-249 field trial, performed at WTD 52, Oberjettenberg, Germany. This facility is equipped with a cable car and is ideal for slant-path experiments between the base station and the cable car, where the sensors to be dazzled were mounted. Laser dazzling took place during dusk and nighttime. The investigation focused on a number of aspects concerned with laser dazzling: aiming accuracy, the influence of light scattering from the aircraft canopy, the detection of laser irradiation, the influence on optronic systems, and protection against laser irradiation.

Laser propagation is subject to atmospheric effects, which is one of the topics focused on by the Signatorics department at Fraunhofer IOSB. Laser sources for various applications are developed by our Laser Technology department. The Optronics department researches into the effects of laser dazzling on optronic sensor systems and corresponding protection measures. And, last but not least, the Object Recognition department investigates its impact on image exploitation.

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Detecting alterations to linear-type infrastructure

Roads, railroads, power lines, pipelines, dams or levees are critical installations. Aerial photography is used to check the integrity of such infrastructure. In order to simplify this process, we have developed a new module for our ABUL system, which provides automatic analysis of images recorded by unmanned aerial vehicles. This module analyses two or more series of images recorded at intervals of several hours or days and detects any differences that could indicate structural damage.

Our preliminary investigations showed that the flight pattern of a UAV can be systematically reproduced to a degree of exactitude that satisfies the requirements of change detection. The major challenge is to locate the exact reference images within a large volume of data. This was accomplished with the VABUL video database. We then evaluated two different methods of change detection: video-based change detection, in which two video films are registered to one another and compared on the basis of their coverage of the same scene; and mosaic/single-image change detection, in which individual images are registered to one another and compared.

In terms of being able to detect changes in the images, the system is promising. However, it still has difficulty distinguishing relevant changes in the images from changes in image quality resulting from, for example, shadows. To remedy this, we are using deep learning to teach the system how to recognize and filter different classes of object. (In the image above, the algorithm has been able to identify buildings, cars, trucks and construction vehicles, visualized by different outline colors).

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ENERGY, ENVIRONMENTAL AND SECURITY SYSTEMS

From sensor data to smart services

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

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

DEPARTMENTS INVOLVED

- ILT
- NRG
- OPT
- OBJ
- SPR
- VID
- WMS

SCOPE

- Cross-sectoral energy systems
- Electricity generation systems
- Energy management systems
- Cybersecurity for energy and water utilities
- Smart water management
- Smart security systems for national, regional and local authorities

SELECTED TECHNOLOGIES

- EMS-EDM PROPHET®
- Cloud-based energy services
- Forecasting and optimization methods
- WaterFrame® – Information Systems
- UVC LED modules for water disinfection
- Machine learning
- Artificial intelligence
- Crowd management
- Activity recognition
- SensorThings API

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iosb.fraunhofer.de/es

"A CROSS-SECTORAL VIEW OF THE ENERGY TRANSITION"

Sensor data management, data analysis, data protection: future challenges require interdisciplinary knowledge and skills

Energy, Environmental and Security Systems – that seems like a broad spectrum. Where is the common ground?

Peter Bretschneider: The sectors share many concerns, not least the energy transition. By 2050, Germany intends to cut its CO_2 emissions by 80 percent compared with the 1990 baseline. This goal cannot be achieved simply by shutting down coal-fired power plants and replacing them with wind or solar energy. Until now, the energy industry has provided the lion's share of CO_2 reductions. In the future, the production, transportation and building sectors will have to do more. That's why we need to take a cross-sectoral view of the energy transition – something our business unit is eminently equipped to do.

Can you quote an example?

Bretschneider: In the Bauhaus.MobilityLab Erfurt research project we are developing an innovative IT ecosystem that combines smart mobility, logistics and energy solutions at a local urban level. It was one of the winning projects in the AI Innovation Competition of the German Federal Ministry for Economic Affairs and Energy (BMWi), out of 135 entries. Solutions like this involve many of the skills that our business unit can provide, starting with IoT sensor technology, data management and user interfaces and extending to issues such as artificial intelligence and IT security. For instance, we can make use of the Fraunhofer Open Source SensorThings API Server (FROST®) for sensor data management, and our established EMS-EDM PROPHET® solution for energy data management, energy forecasts and energy usage optimization. Smart ICT solutions will become increasingly important in the future. Already today, it would be impossible to assure the supply of

electricity without modern grid operation and control systems. Innovative ICT solutions will also enable the emergence of new business models for decentralized energy services such as smart charging stations for electric vehicles and neighbourhood-related power generation.

These solutions involve collecting large quantities of data – something that many companies and private individuals feel uncomfortable about.

Bretschneider: That's true. Data must be protected, but we also need this information in order to perform our work. We use electricity consumption data to predict grid loading, analyze energy efficiency, and plan how to distribute energy as flexibly as possible. An even more sensitive issue is the exploitation of video data, such as that recorded by security cameras. That is why our institute takes great care to ensure that the applications we develop comply with data protection, IT security, and data privacy regulations. As well as cooperating with the Fraunhofer-wide Cybersecurity Lab, we have also set up a dedicated research group to deal with data protection and its enforcement by means of privacy-by-design approaches.

Prof. Peter Bretschneider holds the Chair in Energy Usage Optimization at Ilmenau University of Technology and heads the Energy Systems department at Fraunhofer IOSB.
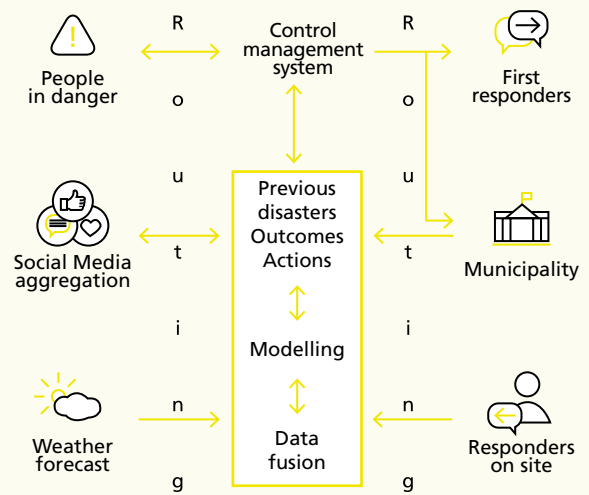
Ecosystem for tomorrow's connected cities

The Bauhaus.MobilityLab Erfurt is a unique real-world laboratory in the heart of Germany that aims to develop and test sustainable and intelligent solutions for mobility, logistics and energy supply with the help of the public. The idea of cross-sectoral connectivity in the Am Brühl district of Erfurt won over the jury of the innovation competition "Artificial Intelligence as a Driver for Economically-Relevant Ecosystems" of the German Federal Ministry for Economic Affairs and Energy (BMWi).

The project was conceived as an interdisciplinary, open ideas workshop. It covers a multiplicity of activities. For example, 500 households have been recruited to test an app that interacts with a smart city platform, and infrastructures are being built for e-mobility and autonomous compact vehicles. A new cloud-based IT ecosystem is also being established to fuse data from different sources and sectors and to edit it in such as way as to enable the creation of new, intelligent services. This software will also be transferable to other real-world laboratories as an open-source, service-oriented, scalable platform, in addition to its original purpose supporting the Erfurt real-world laboratory.

In other words, the Bauhaus.MobilityLab will serve as an open, evolutionary incubator for innovative service and infrastructure projects in the context of the energy transition and changing mobility habits. Four Fraunhofer research groups, Bauhaus University Weimar and nine other partners are participating in this project, which is led by Fraunhofer IOSB-AST.

bauhausmobilitylab.de

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Decision support for dealing with extreme weather and climate events

beAWARE is an EU-funded research project that proposes an integrated solution to support forecasting, early warnings, and management of weather- and climate-related emergencies. The role of Fraunhofer IOSB and its partners in this project is to design a system to collect heterogeneous data from several resources such as environmental data, social media, input from first responders and/or people in danger and semantically integrate and analyze them. The resulting information will be used to provide decision support to the crisis management center. The system will also help with coordination between the first responders and the authorities (see diagram).

Our intention is to rely on platforms, theories and methodologies that are already used for disaster forecasting and management and add the elements that are necessary to make them work efficiently and reliably as part of an integrated solution.

The overall context for beAWARE lies in the domain of situational awareness and command and control (C2). Situational awareness means being able to accurately determine what has happened, what is happening now, and what will come next, all in order to plan and coordinate the most effective response possible with the resources available. The system's operational capability has been tested in simulated large-scale exercises for scenarios including heatwaves, flooding, and extensive wildfires, all with positive results.

beaware-project.eu

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Crowd monitoring, prediction and decision support

Public sporting events, cultural fairs and folk festivals attract large crowds. Dangerous situations may occur due to the large number of people. Organizers of such events are often overwhelmed by these responsibilities, hence the need for new solutions and innovative ideas. As part of the BMBF-funded research project "Safety in urban environments: Crowd monitoring, prediction and decision support", or S²UCRE for short, we have been investigating new emergency rescue and security technologies for events that attract large numbers of people, in collaboration with research partners and potential users in Germany and France.

In such complex situations, hidden dangers lurk everywhere. Our solution combines in-situ video monitoring to measure or estimate the size and density of the crowd, and the rate at which it is moving, including the detection of anomalies, with an ex-situ simulation of the short-term dynamics of crowd movements. We also employ a privacy-by-design approach to preserve individual rights as far as possible. Efficient command and control is assured by means of an intuitive presentation of situational awareness data and software that provides a dynamic analysis of emerging dangers, enabling rescue teams to prepare escape routes and coordinate their interventions. By containing risks more efficiently, better crowd control can be provided. The efficacy of the new solution was successfully demonstrated in 2019 at one of the two reference events: the festival to celebrate the anniversary of the port of Hamburg, during which the organizers ran the system 24/7.

🌐 *s2ucre.de*

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Open-source sensor data platform for analysis and semantic editing

In 2019, Fraunhofer IOSB launched CrossTEP-OPAL, an in-house research project to develop a web-based platform toolbox for the recording, visualization and intelligent analysis of sensor data. This project connects and extends products developed by our institute, such as FROST®, our implementation of the SensorThings API for sensor data management, and WebGenesis®, a framework for the generation and support of web-based information systems, their visualization and semantic integration. Other sources used include Industrie 4.0 knowhow (OPC UA), existing data analysis tools (EMS-EDM Prophet), and activity recognition algorithms for video material.

The project is structured around typical use cases in the fields of video data analysis, energy consumption predictions, the recording and analysis of environmental data, and outdoor localization. These use cases are representative of hypothetical – but realistic – customer projects in the fields of Data Engineering and Data Science. As a first step, the available sensors were integrated and their measurements visualized, using newly developed visualization formats were necessary. In the second year of the project, we are now focusing on developing a framework for integrating algorithms and obtaining deeper insights from the collected data. Thus, the toolbox will offer a web-based data science pipeline that will enable projects involving sensor data to be implemented rapidly and at low cost – from smart city applications and environmental information systems to energy management systems and solutions to improve public safety.
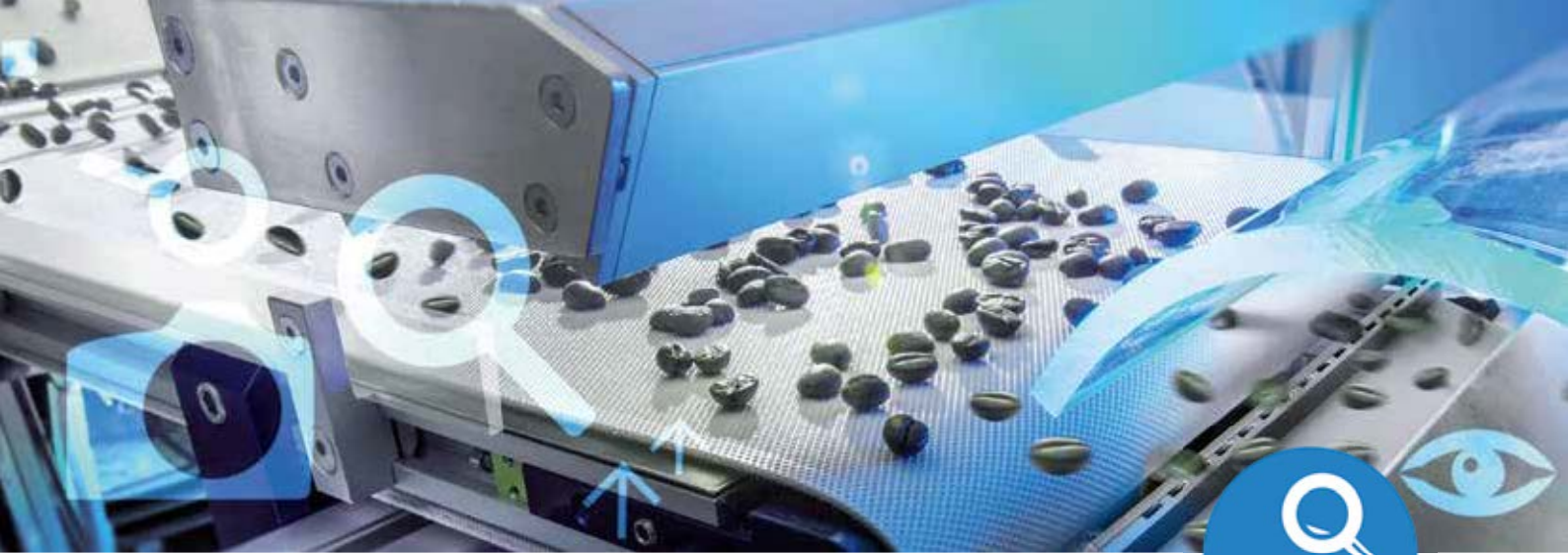
🌐 *iosb.fraunhofer.de/servlet/is/105429*

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INSPECTION AND OPTRONIC SYSTEMS

Assuring quality and increasing productivity by means of machine vision

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

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

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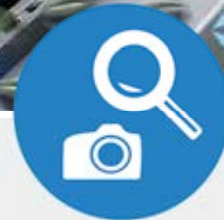
DEPARTMENTS INVOLVED

- MRD
- OPT
- SIG
- SPR
- SZA

SCOPE

- Inspection of complex objects
- Food quality
- Cognitive agriculture (COGNAC)
- Sorting bulk goods
- Remote inspection/monitoring
- Optronic communications

SELECTED TECHNOLOGIES

- Ellipsometry
- Deflectometry
- Multisensor and hyper- spectral image processing
- Multimodal, real-time image processing
- Multi-object tracking
- Optical measurement systems
- Wavelet-based processes
- Purity (automatic inspection of transparent objects)
- Machine learning
- Adaptive optics

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"HELPING TO GUARANTEE WORLD FOOD SUPPLIES"

Expertise in inspection and remote sensing for agriculture and food chains

Professor Längle, sorting systems for items including foodstuffs have long been a key domain of Fraunhofer IOSB. Does the institute have any other connection to food?

Thomas Längle: A lot, really, when you look at our activities. In the field of visual inspection, we have a lot of experience in capturing and analyzing a whole variety of spectral data. We've been collecting spectral data from plants and food-stuffs, for example, for a number of years now. We've also been working for quite a while now on ways of efficiently analyzing remote-sensing data, and we have expertise in robotics and autonomous systems. Besides that, we also have expertise in overarching areas such as AI, sensor technology, data management and system architecture. So taking all that into account, we've got all we need to drive the advance of digitalization in agriculture and right along the food chain.

What does that mean exactly?

Längle: Agriculture is undergoing a profound change. We need new approaches to ensure we can sustainably feed humanity in the face of population growth and climate change. A major hope is that digital technology will help boost the efficiency of food production in an environmentally friendly way. To give you a concrete example: optical or, to be more precise, hyper-spectral sensors systems fitted to agricultural robots, drones or even satellites can be used to automatically monitor the condition of plants and soil on both a large and small scale. Using state-of-the-art algorithms, multivariate analysis and AI, we can determine the health and ripeness of plants, based on the inspection of an individual leaf, or analyze diverse soil parameters. This data is sent to a cloud-like resource called the Agriculture Data Space, where it gets analyzed, along with other data, in order to produce, say, a fertilization and water-ing schedule tailored to the crop's precise requirements. This is a vision our SPR, MRD and SZA departments are working on right now in the Fraunhofer lighthouse project COGNAC (Cognitive Agriculture) and other projects.

What other opportunities are there further down the value chain?

Längle: Not only plants in the field but food products as well can be quickly classified using spectral sensors – whether for sorting newly harvested crops, for real-time control of specific properties, or actually in the store or at the consumer's home in order to check, for example, whether a foodstuff is edible or already spoiled. We're seeking to develop a small, mobile food scanner (see overleaf) – along the lines of the tricorder from *Star Wars* – and thereby ensure that in the future less food ends up in the garbage can because the best-before date has expired.

Prof. Thomas Längle serves as spokesperson for the Inspection and Optronic Systems business unit.

AutoInspect: Surface inspection in the age of Industrie 4.0

Demand is rising for digitally connected measurement data for use in automated process evaluation and automated test procedures. For the inspection of surfaces, this data must be precisely positioned and machine-readable. This data shows the quality of the process used to produce the surface and forms the bedrock for analyses using methods based on machine learning and artificial intelligence.

In a self-financed project, Fraunhofer IOSB is developing a large-scale, modular demonstrator that offers a wide variety of testing methods for surfaces and automates, to a large extent, the configuration process for the inspection of a wide variety of objects. The inspection results are broken down into segments and registered, along with their precise position, on the reference model of the object under inspection, as shown in the image (here with sensor data of parts of the door and three classified markers). Given the complex and voluminous geometry of the objects intended for inspection, and the variety of inspection processes that can be selected for different surfaces, the process will make use of automated guided vehicles (AGV) and robots.

Initially, the following inspection routines will be provided: 3D object scanning (geometric models), scanning methods for transparent and nontransparent surfaces (purity, ellipsometry), inspection of surfaces for reflection effects (deflectometry) and gesture-based registration of defects identified by inspectors. In the medium term, the demonstrator is to be relocated to the Karlsruhe Research Factory, where other processes will be incorporated. In the long term, the intention is to set up a Fraunhofer inspection center for complex products.

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Mobile scanner to improve food product safety

Imagine a pocket-sized device that can quickly and easily test foodstuffs for freshness, authenticity or nutritional value, whether in packaged or unpackaged form. Such a device would have a host of uses right along the entire food chain. In a collaborative research project funded by the Bavarian State Ministry for Food, Agriculture and Forestry, Fraunhofer IOSB has now developed such a food scanner. This device is currently undergoing testing for potential applications.

At the heart of the device is a spectroscopic near-infrared sensor. In addition to determining the degree of ripeness of fresh foodstuffs, it can also be used to detect specific constituents of foodstuffs and the authenticity of products such as olive oil or salmon. The scanner is held to surface of the product or the packaging foil. Infrared radiation is reflected from the surface of the product and captured by the sensor, which compares it with other reflection patterns in a reference database. Using machine-learning methods, an algorithm is trained to be able to classify, on the basis of the spectrum of reflected light, the product's firmness – and thereby its degree of ripeness – or its authenti-city. The sensor was initially trained with tomatoes and meat.

The sensor is made of off-the-shelf, low-cost components. Apart from the scanner, the prototype also features an app and a cloud-based solution for data analysis. At present, the process is limited to homogeneous foodstuffs. In principle, it could also be used for other materials such as textiles or plastics.

🌐 *foodscanner.eu/servlet/is/105098*

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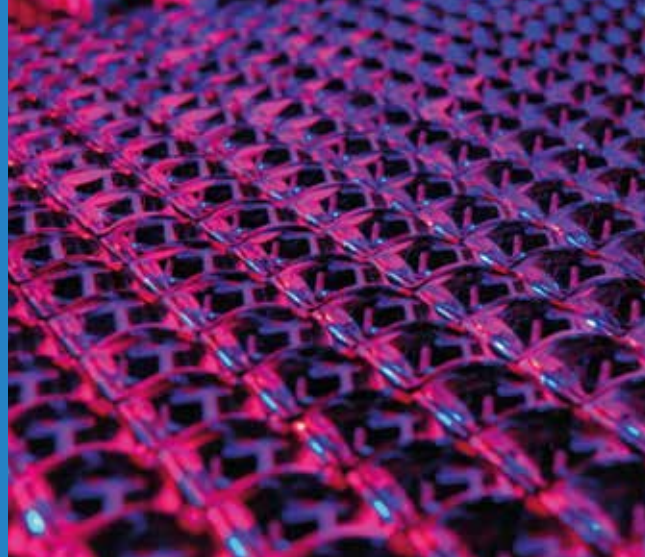
LDV measurement of vibrations of a wind turbine

As everyday experience shows us, the vibrations caused by appliances and machinery such as cars, washing machines or computer fans are a mine of information. The same applies to wind turbines, where vibration sensors are employed during design and development phases as well as for monitoring purposes during actual operation. Yet the difficulty involved in operating such sensors often restricts their use to a bare minimum. For example, permanently integrated sensors often fail before the end of life of the appliance they are monitoring.

Alternatively, a laser Doppler vibrometer (LDV) can be used. When a laser beam is projected onto the surface of a moving object, this light is refracted and undergoes a Doppler effect dependent on the object's velocity. Using an interferometer, the refracted light is compared with the original beam, thereby determining the frequency shift. This technology is commercially available and can be used for remote measurement of vibrations on surfaces accessible to laser projection. For wind turbines, we are developing optimized LDV techniques. This relates to two aspects: 1. Increased range so as to be able to conduct measurements from the ground and at a suitable angle to the turbines, which are often over 100 meters in height. 2. Separation of the vibration signal from the significantly more intense, regular movements, not least the rotation of the rotor blades. For reasons of eye safety, we use a short-wave infrared laser. The signal is filtered and analyzed with a high-frequency analog-to-digital (A/D) converter. Initial trials with the system have shown that it is possible to gather vibration measurements of the rotor blades while the wind turbine is in operation.

🌐 *iosb.fraunhofer.de/servlet/is/26555*

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Light field technology

A light field display simultaneously displays different visual aspects of a scene from different angles. Some game consoles already use this principle to display two images – one for each eye – from a slightly different perspective and thereby generate a 3D image without the need for 3D glasses. At Fraunhofer IOSB, however, we are generating fully customizable light fields for applications in which the image varies according to the observer's position. These can be used, for example, to simulate 3D structures behind the plane of the monitor or to create light sources that illuminate individual areas differently.

A light field emitter is a planar light source in which both the position and direction of light emission can be varied. Our prototype combines a monitor with an array of lenses mounted in front of it at a distance corresponding to the focal length of the individual lenses. Whenever a pixel is activated behind an individual lens, the light field monitor emits a parallel bundle of rays in a direction determined by the position of the activated pixel behind the individual lens. This generates a 4D light field $L(x,y,\theta,\phi)$. The spatial resolution depends on the number of individual lenses in the lens array; the angular resolution on the number of monitor pixels behind each individual lens.

In order to be able to control the light field, it is necessary to know which monitor pixel is responsible for emitting light in a specific direction. The assignment of each monitor pixel to a spatial pixel (individual lens) and a directional pixel (angle of observation) is conducted by means of a calibration routine.

🌐 *iosb.fraunhofer.de/servlet/is/104816*

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DEPARTMENTS

OPTRONICS

SYSTEM TECHNOLOGIES

IMAGE EXPLOITATION

LAS | LASER TECHNOLOGY

Optronics

The Laser Technology department develops laser sources and non-linear converters. Therefore, we design photonic materials and components to optimize infrared laser systems so that they meet the specific requirements of optronic applications.

Research areas and competences

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

Applications and products

Our SWIR and MWIR laser sources can be used as direct emitters in applications such as communication, illumination and metrology. They can also be optimized for pumping non-linear converters, paving the way for high-energy laser sources at other wavelengths. We make our innovations available to other departments at IOSB, where they are used to research and develop optronic and photonic applications, such as evaluating the performance of passive and active optronic sensors and laser protection.

RESEARCH TOPICS

- Fiber lasers
- Nonlinear converters
- Solid-state lasers
- Crystal growth

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58

Installation of new laser laboratories

Our new laboratory boasts state-of-the art equipment for researching and developing 2 µm-emitting fiber lasers. In a cleanroom environment, we use machines such as cleavers, splicers, recoaters and various analyzers to prepare and process active fibers, inspect and qualify them, and to manufacture dedicated fiber components.

The lab also features several optical tables, where we assemble fibers and fiber components using our own innovative laser architectures. Some tables are reserved for high-power continuous-wave lasers, while others are used for pulsed lasers delivering high average power. We use cutting-edge equipment to characterize and qualify laser beams. The laser sources' efficiency, the spatial quality of the beams, their polarization states and their temporal behavior are among the output parameters we optimize to meet the specific requirements of optronic applications.

The department also equips other laboratories dedicated to the development of MWIR solid-state laser sources, non-linear converters in mid- and longwave-infrared wavelengths, as well as crystal growth to provide innovative high-performance active materials. In the near future, when all the labs are fully operational, the department's research teams will be able to collaborate with other IOSB divisions, so that their R&D work can provide a global response to our stakeholders' needs and challenges.

2 µm fiber laser research

Fiber lasers based on active fibers doped with thulium or holmium ions are an efficient way to access the 2 µm wavelength region. They can be used in a wide array of applications, including clinical medicine, materials processing, atmospheric measurements, free-space optical communications, lidar sensors, longer-wavelength laser pumping, countermeasures and high-energy laser weapons. The Laser Technology department's current research and development into 2 µm fiber laser targets three main fields of operation.

1. We are conducting innovative studies on active doped fibers with enhanced chemical and geometrical designs in order to research and develop kilowatt-class 2 µm continuous wave fiber lasers.
2. Other applications require 2 µm pulsed emission together with high average power in different temporal regimes with pulse widths varying from microseconds up to femtoseconds; to achieve this, we test, fine-tune and compare different topological arrangements of fiber and fiber components.
3. We also optimize fiber lasers to pump nonlinear converters in demonstrators.

As one of our most recent achievements, we believe we are the first to demonstrate a Tm-Ho co-doped triple-clad fiber laser in CW and Q-switched operation modes.

1 *Making fiber end caps.*

2 *2 µm Tm-doped fiber laser in operation.*

OPT | OPTRONICS

The Optronics department develops and optimizes active and passive optronic systems and evaluates their performance using both experiments and theoretical models.

Research areas and competences

We research methods and create mathematical models for designing, evaluating and protecting innovative electro-optical sensors. With our laboratory evaluation systems and prototypes of novel sensing methods, we experiment with active and passive optronic sensors and sensor systems to evaluate their performance and possible applications. We use analytical and computational approaches to model sensors and the imaging process, also simulating thermal infrared (IR) scenarios to predict how the sensors will perform in different situations. In addition, we inspect, prepare and evaluate ways to protect the human eye and electro-optical sensors (visual and IR) and to investigate how laser sources might threaten optronic systems.

Applications and products

Our TRM4 thermal range model can calculate the performance of scanning and rigid thermal imaging devices and cameras that use VIS, NIR, SWIR and thermal IR. Valuable in both military and civilian contexts, TRM4 is adapted to changing requirements on an ongoing basis.

Our OSIS and TISIM models simulate static sensor images. They make it possible to substitute high-quality image templates for real-life scenes when evaluating an imaging device. Using advanced image processing, the templates are degraded until the result closely resembles the image that the simulated device would show of the scene.

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

Optronics

RESEARCH GROUPS

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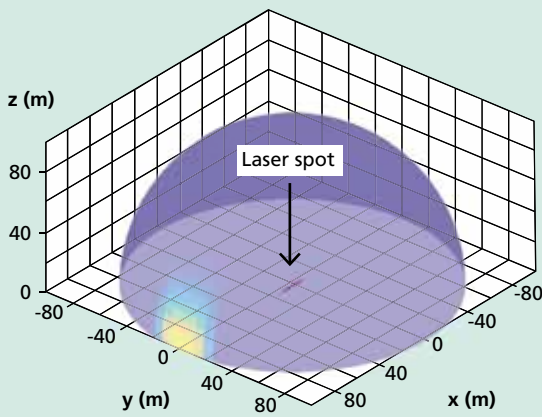- Sensor simulation

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Laser beam propagation in a maritime environment

Using lasers safely, especially in outdoor environments, calls for a complex analysis and understanding of the scene – including identifying areas that could receive light intensities above a critical level.

In a maritime environment, apart from the usual line-of-sight propagation, we also have to take reflections from the sea's surface into account. Conducting outdoor experiments to study reflections from water surfaces in a variety of weather conditions, however, is extremely expensive and difficult.

As an alternative, we are developing a software tool that simulates a maritime scene and calculates laser beam propagation through the atmosphere and its interaction with the sea's surface. The water surface, the atmospheric turbulence and the atmospheric beam scattering are simulated at different levels of accuracy ranging from a rough approximation to highly detailed, depending on what is requested [1]. Ultimately, we will be able to estimate the areas and the statistics for critical exposures.

Quantum ghost imaging for remote sensing

Modern imaging systems for military, security and disaster scenarios are generating a growing demand for imaging techniques capable of returning high-resolution images under adverse conditions [2].

Current active imaging systems combine the illumination of remote objects with time-resolved detection techniques to image objects through scattering and turbulent media. These systems rely on illumination with short laser pulses and detection of backscattered light with background-noise-limited cameras. The success of this traditional approach is limited by eye-safety considerations as well as background noise from the camera system and the environment.

We are developing a detection system based on quantum technology that transcends these and other traditional limits. By exploiting the quantum correlation of entangled photon pairs, it is possible to physically separate illumination and imaging into different parts of the spectrum. With our setup, we illuminate objects in the eye-safe infrared region while they are detected in the visible range using low-noise single photon avalanche detectors (SPADs). Since each object's spatial information is obtained from photons that have never interacted with the object itself, this imaging technique is referred to as quantum ghost imaging [3].

Furthermore, quantum ghost imaging exploits the temporal correlation of the entangled photon pairs to separate signal photons from noise and achieves a noise-free imaging scheme.

[1]   Schwenger, F.; Scherer-Negenborn, N.; Braesicke, B.: Simulation of the interaction of a high energy laser beam with the sea surface in the short wavelength infrared, Applied Optics Vol. 58, Issue 29, pp. 8126-8140 (2019), https://doi.org/10.1364/AO.58.008126

[2]   Göhler, B.; Lutzmann, P.: Optical Engineering, 56(3), 031203 (2016).

[3]   Pittman, T. B.; Shih, Y. H.; Strekalov, D. V.; Sergienko A. V.: Phys. Rev. A 52, 3429 (1995).

1 The hemisphere represents the reflected laser power at a distance from the laser spot (in red) on the ocean's surface. The color code – from dark blue to green to orange and finally yellow – indicates low to high energy.

2 Our quantum ghost imaging experiment: A special crystal (on the right) converts laser light into entangled pairs of photons, each consisting of one photon in the infrared and one in the visible range. The former ones illuminate the object, the latter ones are detected with high spatial resolution by a silicon chip (left).

SIG | SIGNATORICS

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

Research areas and competences

Our research focuses on warning sensor technology, adaptive optics, the evaluation and 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 atmospheric propagation of light. We identify adverse effects on systems operating within the UV to the IR spectral bands and develop hardware and software to overcome these effects. Our expertise in multi-spectral threat signatures allows us to design, assess, and optimize innovative sensor technology. We research and develop techniques to minimize one's own signature (camouflage) and generate false signals (decoys).

Applications, products and services

Our expertise has both civilian and military applications. We develop innovative approaches, driven by advances in detector technology, 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 laser communications. Our laboratory and field measurement equipment lets us determine optical materials and system properties within the full spectral range.

Infrastructure and lab facilities

Field trials based on our own ground-, sea- and air-based sensor systems and measurement techniques are an important aspect of our work. Our adaptive optics test-bed lets us simulate and correct for atmospheric turbulence. In our underwater turbulence laboratory, we carry out experiments with exotic states of light propagating in water, which has applications in covert underwater communications. We also operate a robot-driven setup to automatically measure bidirectional reflectance distribution functions (BRDF). Finally, our environmental simulation lab lets us account for solar radiation, sky coverage, and cross wind in assessing signatures.

RESEARCH GROUPS

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

SIG

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Adaptive optics for free-space communications

The potential of free-space optical communications in civilian and military contexts is vast. However, such systems are severely limited by atmospheric effects. We work to counter these effects and enable high-data-rate terrestrial and space-to-ground optical communications.

The advantage of free-space laser communication technology is that it does not depend on fibre between the terminals. This makes it a promising solution to the "last mile" problem, i.e. providing bandwidth in rural regions and emergency services in remote areas, especially in combination with satellite links. Military applications include the ability to transfer intelligence, surveillance, and reconnaissance data effectively. Laser-based satellite and deep-space communications are a special case. Observation satellites are everywhere, and their imaging sensors produce vast quantities of data. So what about the data traffic back to the ground terminals? A low earth orbit satellite can produce up to 10 terabits of data per day. The typical bandwidth of an X-band channel is currently around 800 megabits per second, implying that the satellite would have to spend at least 15 percent of its time in the sightline of the ground terminal, using up all of its bandwidth just to transmit its data.

The atmosphere can have a major impact on the performance of laser-communication systems. Apart from completely disruptive phenomena such as rain and fog, turbulence affects the power delivered and the number of errors in the transmission. Fraunhofer IOSB addresses this problem with advanced adaptive optics (AO) technology. In the AO laboratory, we develop solutions to the most challenging issues of laser propagation through serious turbulence. We are currently investigating holographic wavefront sensing, wavefront-sensorless AO, and adaptable Shack-Hartmann sensing. Our labs test these strategies in simulated and real environmental conditions.
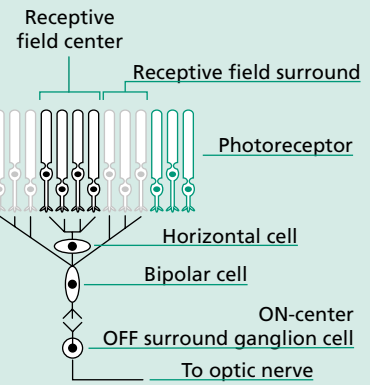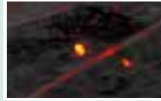
Assessing camouflage using a conspicuity rating inspired by biology

For military units, good camouflage reduces their chances of being detected and makes it harder and more time-consuming to identify them. Assessing camouflage and finding a way to rate conspicuity quantitatively is vital to their very survival. Since camouflage is designed to foil not only human observers but also the artificial neural networks in use as of late, we focus on both biological and artificial image processing.

We model neuronal structures in the human visual pathway that respond to local anomalies in images. This helps us rate the visual attraction of regions in images or videos. With no prior knowledge of where the objects are positioned, our model accounts for a range of factors – local discontinuities, textural similarites of objects compared to the background, and the transition between object and background – as it processes the whole image in different spatial sampling resolutions. This lets us rate the conspicuity of camouflaged objects in relation to the background, and yields local conspicuity values for a large set of statistical parameters for each image that are biologically significant. These can be combined to form an overall visual conspicuity map. Going forward, the model will use eye-tracking fixation maps to resemble a human observer's performance more closely.

We also investigate the effect of camouflage on convolutional neural networks designed for object classification, both self-trained and pre-trained. These methods are currently being used on static images as well as flight approach videos.

1 *Design of the new Laser Communications Laboratory.*

2 *Calculating local conspicuity (highlighted in red to yellow in the bottom left image) using a modelled neuronal structure of the human visual pathway (right).*

SPR | VISUAL INSPECTION SYSTEMS

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

Research areas and competences

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

Applications and products

We develop systems that sort bulk goods automatically. They are used in recycling (e.g. glass, plastic, 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 tablet blister packs. Currently, we are working on a mobile food scan-ner that uses NIR spectroscopy to check the composition, freshness and quality of foodstuffs.

Infrastructure and lab facilities

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

RESEARCH GROUPS

- Sorting systems for bulk goods
- Inspection of complex products
- Food quality and agriculture
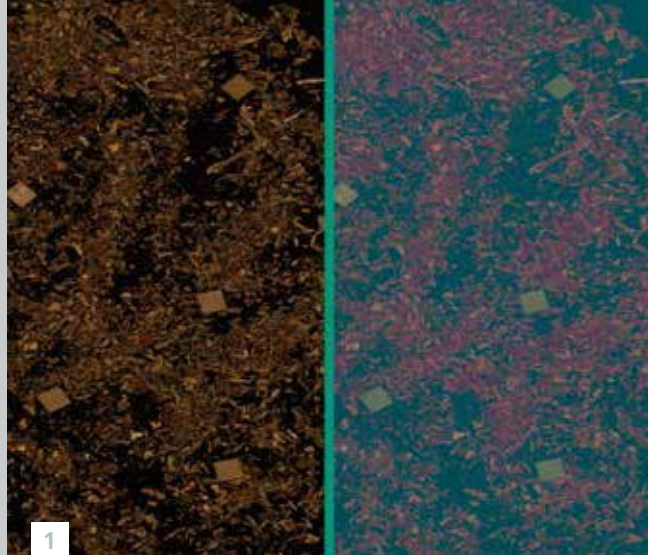
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Using machine learning to reliably detect foreign bodies in natural bulk goods

Machine learning has the potential to master many challenges in visual inspection. One option we use is employing data-driven procedures to distinguish the different materials' spectra from one another. When challenges are especially demanding, a sufficient number of data points need to be gathered to train an appropriate classifier. On top of that, knowledge of the specific domain to which a given task belongs must also be figured in. To achieve this, we work closely with our customers to integrate this knowledge and also leverage our contacts at other Fraunhofer institutes. This is the key to mastering tasks such as classifying wood, plastics, minerals, foodstuffs and tobacco.

A case in point: sorting tobacco, which calls for removing foreign bodies that look very similar to tobacco in the RGB color spectrum. By using an RGBN camera (RGB + near-infrared channel) and classic machine learning procedures, however, we can make the foreign bodies visible. To achieve this, we use a process known as dimension reduction to transform information from four channels to three. This yields an image with false colors that puts the information together in the ideal way to perform this particular task. Preprocessing hardware performs the transformation in real time, making it useful for industrial sorting systems.

Detecting pyrrolizidine alkaloid-containing weeds in crops

Pyrrolizidine alkaloids (PAs) are secondary matter that plants produce to protect against insect herbivores. PAs also cause liver damage. When harvested unintentionally along with products such as organic and herbal teas, they can result in problematic alkaloid exposure, which is why the PA limits considered safe were tightened in recent years. As a result, as few as four to five PA-producing plants per hectare may be

enough to endanger the entire crop's marketability as a medicinal product. Since monitoring fields in the continuous, regular manner necessary and removing the weeds mechanically is hardly economically feasible, downstream quality control of these harvests is an important way to remove potential PA-containing plants.

In a joint project sponsored by the Fachagentur für Nachwachsende Rohstoffe (FNR), we are working with the Julius Kühn-Institut Berlin (Institute for Ecological Chemistry, Plant Analysis and Stored Product Protection) to develop a viable detection method. It aims to use hyperspectral near-infrared spectroscopy to detect contamination by weeds containing PAs in harvests of medicinal and herbal plants. Early experiments have shown that it is possible to classify varieties of plants using NIR spectroscopy. The aim is to sort out the unwanted plants in an optical bulk goods sorting system with this technology. We are currently developing a prototype to purify harvests in real time that will make lowering the health risks posed by PA-contaminated medicinal plant products environmentally friendly and economically feasible.

1 Wood and tobacco: while barely distinguishable in the RGB image, they show a clear contrast in the transformed four-channel image.

2 Blended sample of target plants and unwanted PA-containing plants. In the hyperspectral image on the right (false color image), the blue tint makes the unwanted plants easy to identify.

DIS | DIGITAL INFRASTRUCTURE

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

Research areas and competences

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

Applications and products

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

Infrastructure and lab facilities

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

RESEARCH GROUPS

- Intelligent sensor systems
- Industrial communication & IoT
- Cybersecurity in production

DIS
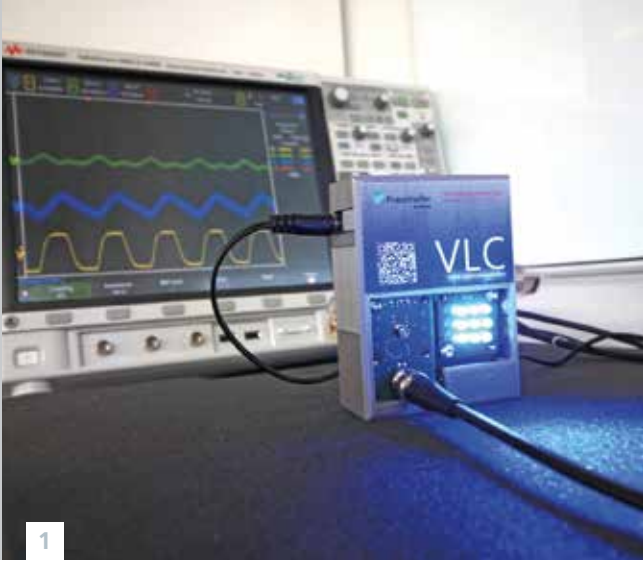
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Visible light communications for industrial production facilities

Manufacturing today is thoroughly networked: production machinery, conveyor systems, robots, sensors, monitoring systems and mobile terminal devices all communicate with one another and exchange data. This growth in the number of field devices that are connected within the production environment is stretching conventional wireless technology to its limits. The bandwidth provided by Wi-Fi and Bluetooth is limited, and not even 5G will be able to meet every demand.

Visible Light Communication (VLC) is an alliance project funded by Germany's Federal Ministry for Economic Affairs and Energy. Launched in 2018, its purpose is to investigate the use of the visible light spectrum for wireless data transmission. In this technology, data is transmitted by an LED and received by a photodetector, which converts the light signal into electrical pulses. By examining the challenges involved, the project is seeking to define the requirements for the use of VLC in an industrial setting and to describe possible scenarios.

While signal interference is the major issue in data transmission, other possible sources of disruption include artificial light and the shadows or reflections caused by walls, metallic objects and machinery. A series of measurements has shown that dust particles, people or slow-moving vehicles (0.2 m/s) do not pose any problem. Sources of ambient light such as fluorescent tubes, welding lamps or optical tracking systems affect the entire optical spectrum, but only on a local level. Here, tests showed that VLC systems are able to adapt to the lighting conditions, thus minimizing the impact of such interference. By contrast, reflections are a cause of significant interference, since they lengthen the propagation time of the light signal and distort it in the nanosecond range, thereby diminishing transmission quality. On the basis of quantitative measurements, we and our project partners are now developing environmentally adaptive VLC systems for industrial use.

Making industrial connectivity more flexible and secure

To implement the paradigms of Industrie 4.0, we will need production systems that are significantly more flexible than those in conventional industrial facilities. And we must ensure that these systems have real-time capability and the requisite cybersecurity specifications. This requires research into methods for configuring production systems on a dynamic basis. In the FlexSi-Pro project, we are applying software-based methods of network control to industrial environments so as to leverage the added flexibility this technology provides. In order to deliver high standards of real-time communication and cybersecurity, we are looking at a combination of technologies such as software-defined networking, time-sensitive networking and OPC UA.

The project aims to design, evaluate and demonstrate software-defined networks for the connectivity of future production plants. Such technology will enable a network administrator to manage data traffic centrally by means of control software and without the need for manual access to network components on the production site. We first defined use cases and drew up a list of what future production facilities will require for full industrial connectivity. On this basis, we produced a generic framework that now serves as a platform for the development of flexible Industrie 4.0 production systems. Technical implementations of this have already been demonstrated. One demonstrator automatically incorporates a camera application in the network and configures the infrastructure in such a way that time-critical information always arrives at its destination on time. Another focuses on security aspects and, if required, will dynamically revoke access to data traffic for specific network participants.

1 *The VLC box is used to analyze optical components, the use of light modulation for light-based data transmission, and the impact of interference signals.*

2 *Flexible, Industrie 4.0-compatible systems must be real-time capable, dynamically configurable via software and nonetheless secure. FlexSi-Pro has demonstrated how this can work.*

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.

Research areas and competences

Our R&D projects in the field of software architectures for computer-based assistance systems focus on dialog design and semantic interoperability. We contribute in this way to the technical networking of systems and their content. Using multimodal and multimedia interaction technologies, we tailor dialogs to suit specific users and tasks, which facilitates collaboration. Our ontology-based 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, including the use of serious games, give users the decision-making abilities they need. Our capabilities include designing, implementing and evaluating system solutions for interactive sensor data analysis; creating knowledge and integrating it into expert systems to support networked data analysis; and modeling users, workflows and application domains. We also specialize in competence management in distributed systems.

Applications and products

We build components for interactive image analysis, ontology-based specialist databases, network-enabled information management systems, and training and education systems. Compliance with and monitoring of domestic and international software quality standards is integral to our development activities. Many of our partners and clients belong to the defense and civil security sectors.

Products we have developed include CSD (Coalition Shared Database), a client-server system that distributes information relevant to reconnaissance among NATO partners; i2exrep, a tool that uses databases to generate reports that comply with standardized reporting formats; AMFIS, a generic, modular ground control station that can coordinate mobile sensor carriers and evaluate sensor data and situation reports; and Lost Earth 2307, an adaptive serious game framework that trains image interpreters and other specialists.

RESEARCH GROUPS

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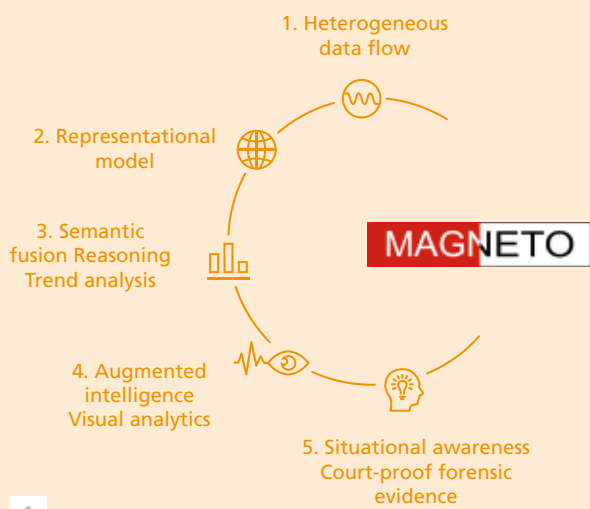

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Data analysis for enhanced crime prevention

Launched in 2018, MAGNETO (Multimedia Analysis and Correlation Engine for Organized Crime Prevention and Investigation) is a three-year EU research project. Its purpose is to enhance the ability of law enforcement agencies to prevent and combat organized crime and terrorist organizations.

To achieve this goal, the project involves developing tools designed to process and analyze large volumes of heterogeneous data, thereby significantly expediting the investigative process. These tools perform tasks ranging from evaluating the available information, securing evidence and fitting together individual items of evidence through to preparing the court file.

Crucial here is the ability to fuse information from a range of sources such as video, audio, text, social media, telecommunications, surveillance systems and police databases. At the same time, using analytic tools and a knowledge model helps improve situational awareness.

Enhancing situational awareness in maritime environments

OCEAN 2020 (Open Cooperation for European Maritime Awareness), launched in 2018, is a project involving research and industry partners from a total of 15 EU member states. Together with these partners, Fraunhofer IOSB has developed a technology demonstrator for maritime surveillance missions and the prevention of hostile maritime maneuvers. With funding of 38.5 million euros, OCEAN 2020 is the largest project within the EU's Preparatory Action on Defense Research (PADR) – an initiative leading up to the introduction of a European Defense Fund for the promotion of European research in this field.

The purpose of this three-year project is to broaden the ISTAR (intelligence, surveillance, target acquisition and reconnaissance) capabilities of naval vessels through the use of unmanned systems and their integration within the vessel's command and control system.

Work will also focus on improving processes for the fusion of information with heterogeneous data and on developing the EU's own C4ISR architecture as a common platform for all command and control systems. The latter will be based on open architecture and standards so as to guarantee interoperability between EU-led and NATO-led forces. A further aim is to integrate fused sensor data into the plot known as the recognized maritime picture and to generally improve situational awareness in maritime environments. These new capabilities will be demonstrated in three simulated exercises and two live demonstrations in the Mediterranean and the Baltic.

1 *Architecture of the Horizon 2020 research project MAGNETO (Multimedia Analysis and Correlation Engine for Organized Crime Prevention and Investigation).*

2 *By fusing data from different sensors and integrating it into the recognized maritime picture, OCEAN 2020 will improve ISTAR capabilities.*

ILT | INFORMATION MANAGEMENT AND PRODUCTION CONTROL

System Technologies

The Information Management and Production Control department develops open and secure architectures, software components and solutions for information, control and test systems in application domains of the Internet of Things (IoT).

Research areas and competences

We implement open, innovative, customized software solutions that drive new paradigms in the Industrial Internet of Things (IIoT) and in Industrie 4.0. Building on agile methods in requirement analysis, system design and recognized architectural and communication standards, our work also goes beyond manufacturing, extending to the environment, health, risk management, resource efficiency and security. We design solutions to address specific issues including machine learning methods, efficient search and processing of heterogeneous data sets, semantic annotation and the fusion of sensor data into meaningful technical information to support decision-making. We are also leaders in IT security for industrial production.

Applications, products and services

Our ProVis 4.0 suite comprises integrated production control systems designed to meet the needs of manufacturing execution systems as well as requirements emerging from IIoT / Industrie 4.0. We are driving forward the development of open62541 and the FROST® server (next page). We develop AI-based thematic components and connect them to environmental information systems such as WaterFrame® and smart city applications. These are built on our ontology-driven information management system WebGenesis®. We offer IT security consulting and training, and play an active role in the Standardization Council Industrie 4.0 and other standardization bodies such as the OPC Foundation, AutomationML e.V., Bitkom, VDI/VDE, DIN, IEC, IIC, W3C and OGC.

Infrastructure and lab facilities

With the Smart Factory Web, an IIC testbed, we are advancing the concept of marketable solutions that use open standards to visualize production capacities and assets in industrial manufacturing. We use various test centers to advance our research activities, such as our Industrie 4.0 model factory, an AutomationML test center, a security testing environment for automation and communication components (ISuTest), and an HLA-based certification test center for distributed simulation federates. In addition, we run an IT security lab.

RESEARCH GROUPS

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

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Open Sensor Data Management with FROST®

Sensor data is undoubtedly the most important building block in the Internet of Things (IoT) – a "thing" in this context being any physical or virtual object that provides information (observations) about a "feature of interest" in its environment. Given the enormous variety of things involved, standards are crucial in order to maintain consistency through the whole chain of data acquisition, validation, contextualization and information processing. SensorThings API is an Open Geospatial Consortium (OGC) standard that uses long-established concepts in sensor data description, while also meeting modern requirements for efficient interfaces.

We decided to develop an open source implementation for the SensorThings API. The parameters: it needed to combine high performance with low resource consumption, and at the same time be open source to facilitate usability in research as well as in commercial applications.

The result is FROST® – the Fraunhofer Open Source Sensor-Things API Server. As the acronym suggests, it keeps data "fresh and available." FROST® has attained the status of an OGC reference implementation and is widely accepted in the geospatial community. It is in use in various environmental projects, including BRGM's French water information network, air-quality data in Taiwan and as a web-based API for our WaterFrame® information systems, as well as smart city applications in places such as Hamburg and Munich. In our role as co-chairs of the OGC working group, we in turn drive forward both the evolution of the SensorThings API standard and its open source implementation. This places us in an excellent position to respond to our customers' needs.

Industrial Communication with OPC UA and open62541

The German initiative known as Industrie 4.0 refers to the application of IIoT principles to industrial production. The Industrie 4.0 platform aims for interoperable solutions and takes an open approach. One of the core technologies is the IEC standard 62541 OPC UA.

We are fully on board and have developed major components of open62541, an open source, free implementation of OPC UA [1]. open62541 is a C-based library (which can be linked with C++ projects) with a small footprint. It features all the tools necessary to either implement dedicated OPC UA clients and servers, or to integrate OPC UA-based communication into existing applications. open62541 supports client/server as well as publish/subscribe (i.e. brokerless) interaction patterns. It runs on Windows, Linux, QNX, Android and various embedded systems. Server implementations based on open62541 have been officially certified by the OPC Foundation to conform with the organization's Micro Embedded Device Server profile supporting OPC UA client/server communication, subscriptions, method calls and security (encryption) with basic security policies and the "method server" and "node management" facets.

Our current focus is on extending OPC UA's security features (especially implementing the Global Discovery Service) and technological mapping to Time Sensitive Networking (TSN) to enable deterministic and real-time communication.

[1] http://open62541.org

1 *In environmental risk management we systematically analyze the requirements of multi-stakeholder use cases and implement them based upon information models and services of the Open Geospatial Consortium (OGC).*

2 *For the Industrie 4.0 we conceptualize digitalization and implement secure networking of manufacturing processes – such as in our model factory shown here – based upon international standards.*

MRD | SYSTEMS FOR MEASURE-MENT, CONTROL AND DIAGNOSIS

System Technologies

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

RESEARCH GROUPS

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

Research areas and competences

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

Applications and products

In process and manufacturing engineering, we develop tools that use machine learning to monitor, control and optimize complex processes. We also develop monitoring and optimization modules for water/wastewater and energy infrastructures. In surface inspection, we research image-based techniques such as deflectometry, optical imaging measurement and evaluation concepts, and automated microscopy. In robotics, we focus on techniques for localization and mapping, including environment-interactive path and trajectory planning, safe physical human-robot interaction and controlling complex robotic kinematics. Applications for these technologies include inspection, logistics, security, precision farming, decontamination, and operations in hazardous environments. Our automotive focus is on developing a simulation platform for virtual test drives; we also use ground and aerial video analysis to build statistical models of road users' behavior, and design concepts and algorithms that pave the way for autonomous and cooperative driving.

MRD

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Infrastructure and lab facilities

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

ML4P architecture

Capturing data, information and knowledge	1
Interactive analysis	
Training appropriate ML models	
Using ML to improve processes and in engineering	2

1
Legacy data
Online data (streaming)
Description of facility
Expertise, etc.

2
Process models
Process parameters
Control variables (on-/offline)
Process monitoring, etc.

Robotic systems for decontamination tasks

Contamination with radioactive or chemical substances can have serious consequences for humans and the environment. So thorough decontamination is vital in the decommissioning of nuclear power plants and the remediation of contaminated sites. The people carrying out this work are subject to physically demanding conditions and may be exposed to severe health risks.

Getting humans out of these hazardous environments is the objective of ROBDEKON, a project that was launched with the aim of establishing a national competence center for "Robotic Systems for Decontamination in Hazardous Environments". In ROBDEKON, which is coordinated by Fraunhofer IOSB, we work with partners from academia and industry to engineer practical robot systems capable of performing the tasks involved in decontamination.

Our research includes the development of mobile robots for rough terrain, autonomous construction machines and robot manipulators. It also extends to decontamination concepts, planning algorithms, multisensory 3D mapping of the environment and teleoperation using virtual reality. Thanks to ROBDEKON's effective algorithms, standard heavy machinery can be equipped with autonomous capabilities. These include basic functions like autonomous driving as well as advanced capabilities like autonomously performing decontamination tasks, e.g., removing a layer of soil.

Machine Learning for Production (ML4P)

The Fraunhofer lighthouse project "Machine Learning for Production" brings together six Fraunhofer institutes under the coordination of Fraunhofer IOSB. The group is developing a tool-aided process model and implementing interoperable software tools that can systematically exploit ways for machine learning (ML) to optimize production processes. By introducing

ML methods, we can identify previously unknown correlations in process data, derive reliable, data-driven process models and establish adaptive mechanisms that make production systems more flexible and open for short term reconfigurations.

In contrast to well-established ML applications that involve significant amounts of data of similar origin of data – image processing, speech recognition, social media and the like – industrial processes generate merely a "large quantity" of rather unstructured data requiring in-depth expertise for its interpretation. Optimizing these complex systems thus calls for an integrated approach which seeks to continuously merge process data with human expertise. While the trend topic of deep learning is of interest in this context, there are also a wide range of other specially adapted ML methods that can work with less data while simultaneously mining troves of existing knowledge.

Based on various Fraunhofer institutes' experience, there is a great demand for this approach both in the processing industry and in manufacturing of standardized products – a demand that is often coupled with a lack of ML expertise on the part of operators. ML4P aims to specifically address these issues by adopting ML methods for manufacturing environment and by developing a process model for their sustainable deployment. The MRD department's R&D focus is on developing a software architecture that enables the application of machine learning methods in the production environment.

1 *IOSB.BoB autonomous excavator.*

2 *ML4P architecture.*

MIT | MACHINE INTELLIGENCE

System Technologies

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

Research areas and competences

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

Applications and product

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

Infrastructure and lab facilities

The SmartFactoryOWL, a joint initiative of Fraunhofer IOSB-INA and the University of Applied Sciences and Arts in Ostwestfalen-Lippe, forms the Machine Intelligence department's main research infrastructure. The systems in operation there deliver large amounts of production-relevant data and are used for developing and testing prototypes for new assistance systems and interfaces. Our Big Data Lab features cutting-edge facilities and capabilities.

RESEARCH GROUPS

- Machine learning
- Big data platforms
- Assistance systems

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KnowledgeBrowser: Industrial process data at a glance

Generating added value from industrial data is a challenging proposition. It is not always clear what data is available or in what form, to say nothing of what it all means. In addition, the infrastructure that can integrate the data into the appropriate services is often lacking. On top of that, the systems and technologies on the shop floor are often a heterogeneous mix, which adds an extra layer of complexity.

The KnowledgeBrowser enables digital services and users to find essential process data on the shop floor and receive it. It indexes existing data, makes it searchable and passes it on to its final destination. Data is integrated primarily via OPC UA. Additional knowledge is added through the Asset Administration Shell. It is continuously checked for any changes in the data on the shop floor, which are then synchronized with the knowledge databases. The system where the knowledge or metadata is stored is an elastic database. An elastic API lets users and services query the databases. The services can communicate with the databases directly, while users can search manually with a web tool.

The selected data, necessary configuration information and target services are sent to a middleware program to establish the data flow. It creates and maintains the containers for the OPC UA data subscription and transport. This pipeline transmits the data from the shop floor to its designated destination. Finally, the services can use the selected data to generate value added. Overall operation is documented to make sure that no resources are wasted by duplicating existing data subscriptions or transmissions.

With the KnowledgeBrowser, companies can find and integrate the data available on their shop floor easily, so they can put it to work to enhance production.

XTEND: Multimodal support in production, job training and maintenance

Assistance systems are intended to counter the increased complexity that digital transformation, enhanced flexibility and decentralization have brought to production. They do this by giving workers the information and help they need to perform specific tasks, right at their work stations. Our XTEND software platform accomplishes this by combining the advantages of various modes of interaction used to support industrial activities. The product family comprises: XTEND|assembly (to guide the user through assembly processes), XTEND|mobile (to enable operation and maintenance of machinery via tablet or data glasses) and XTEND|remoteSupport (to connect work stations irrespective of their location).

Building these products required the use of object tracking in order to ensure proper reproduction in augmented reality (AR). We also developed a cloud database to connect the various software modules. In order to ensure that the platform remains useful in the long term, we developed an editing system with which even users with no coding skills can create and configure content. This project included workshops with participants from industry, research and education.

Aside from the technical work, another key aspect of the project was the development of new fields of application. For example, the software platform can now also be used to help people with disabilities to perform certain tasks. Similarly, the scope of XTEND|mobile has been further expanded to include job training.

1 *The KnowledgeBrowser makes industrial process data more transparent, searchable and therefore much more useful for monitoring and other purposes.*

2 *Hardware- and application-independent: the XTEND system is used for assembly assistance, job training, service and maintenance, and commissioning.*

NRG | ENERGY SYSTEMS

System Technologies

The Energy Systems department develops innovative ICT solutions that are designed to facilitate the energy transition to a flexible, sustainable and cross-sectoral system based on renewable sources.

Research areas and competences

With our specific expertise – in cognitive and integrated energy systems, energy informatics, AI-based decision-support systems, system analysis and design, digital twins and convergent IT infrastructures – we are ideally placed to meet the challenges of the energy transition, especially in the electricity market. This shift, which is driven by power generated from renewable and often highly fluctuating sources, is founded on an integrated approach to the three sectors of power, heat and transportation. We also offer services related to cybersecurity for energy and water supply – a topic increasingly significant in the wake of the digitalization of the energy market.

Applications, services and products

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

Infrastructure and lab facilities

Our research facilities, located in the new Fraunhofer building in Ilmenau, include an energy market lab, a control technology lab, an IT security lab and an energy technology lab.

RESEARCH GROUPS

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

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A technology platform for efficient residential neighborhoods

The smood® ("smart neighborhood") growth hub is a Thuringia-based alliance of 17 companies, four research establishments and a nonprofit organization. Its purpose is to develop an innovative technology platform that will enable property developers, energy companies and residential tenants to realize efficient and environmentally friendly neighborhoods offering a high standard of living. Existing neighborhoods will create their own electricity grids featuring a high degree of self-sufficiency in terms of local power supply.

Such projects will employ energy and control technologies provided by the smood team while also making use of existing infrastructure. smood offers an integrated, digitalized planning process, ranging from innovative neighborhood storage systems for electricity and heat to solutions for control and operational management as part of a systemic value creation concept. These improvements will increase the energy efficiency, utility and desirability of the properties being renovated and may also reduce the total cost of renting (including heating).

We are working on the joint project smoodACT, which aims to achieve energy savings of at least 15 percent through cross-sectoral management of the neighborhood energy network and to halve the costs required for network development by tapping into opportunities for greater flexibility within the neighborhood.

In addition, there are plans to develop and trial a whole range of cross-sectoral energy services for buildings and entire neighborhoods. Based on the smoodACT energy management system, these range from tenant/owner utilization of locally generated electricity to virtual power plants and smart recharging of electric vehicles. Prof. Peter Bretschneider, head of the Energy Systems department, is scientific spokesperson of the smood alliance.

Cybersecurity training lab for the energy and water industries

The energy and water industries rely increasingly on IT systems and automated processes. As such, they are more vulnerable to cyberattacks. Areas that are particularly susceptible include distribution grids and components as well as certain network protocols. Scenarios range from undetected data theft and individual system failures to the ongoing disruption of company operations and supply outages. Effective protection against such threats requires an analysis of vulnerabilities in planning and operation, thorough risk assessment and the implementation of preventive measures. This includes not only technical safeguards but also training for managers and personnel in order to facilitate the development and implementation of suitable security procedures at the organizational level. In addition to our customized in-house training courses, we also offer a training program covering the following areas:

- IT security in the energy and water industries
- Protecting power grids against cyberattacks
- Secure configuration of automation systems in the energy industry
- IT security management in the energy and water industries
- IT security officers in the energy and water industries
- Secure data communications in the energy market
- Data protection for data managers in the energy industry

Among the first customers for our customized in-house training programs in 2019 were the power companies Thüringer Energie AG and Vattenfall AG.

1 *Launch of the smood growth hub in front of the Klimapavillon in Jena.*

2 *Our cybersecurity training lab for the energy and water industries is used also for real-time simulation of dynamic effects in power grids carrying a large share of renewable energy.*

WMS | WATER AND MOBILE SYSTEMS

The Water and Mobile Systems department examines water supply systems in a holistic, integrated approach, and develops embedded and assistance systems along with autonomous land and underwater vehicles.

Research areas and competences

Our work on water systems covers the whole cycle from drinking water abstraction, treatment and distribution to wastewater recycling and sludge treatment. We predict water demand, create model surface water systems and devise concepts to build and rebuild reservoirs, dams and other water systems as well as flood warning systems. In recent years, we have also established a new research area: disinfection with UV-C LEDs. Our expertise in embedded and mobile systems comprises the development and integration of sensors, actuators and other components; guiding and diagnostic systems; and software development for real-time systems, including sensor data fusion and simulation. We are particularly experienced at designing, engineering and building remotely operated and autonomous underwater vehicles for exploration and inspection.

Applications and products

The department's portfolio of competences is as broad as the uses to which our products are put. Our MISO (Multivariates Inspektionssystem für Offshore-Bauwerke) inspector is a multivariate inspection and analysis system used in the offshore industry, while our RTLS flares are used inside buildings to aid navigation. Our LocSens multi-sensor system is designed for the observation of rough industrial settings. Much of our widely varied expertise comes together in our work on autonomous systems designed for hazardous environments. We develop ROVs and AUVs and send them out on test drives – performing archeological explorations under water, for example. We produce models designed to optimize operations in aquaponics systems. And we also succeeded in discovering and demonstrating new uses for UV-C LEDs, such as disinfecting beverage bottle caps.

Infrastructure and lab facilities

We have a variety of robot submarines and surface vehicles at our disposal. In order to test our maritime systems and components, we have a 12x8x3-meter research water basin and a 1200-bar pressure testing facility. In addition, we maintain labs for electronics, rapid prototyping and autonomous robot and assistance systems.

System Technologies

RESEARCH GROUPS

- Embedded systems
- Maritime systems
- Water management solutions

WMS

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Autonomy kit gives conventional vehicles connectivity and capacity for assisted removal of hazards

When accidents involving radioactive, chemical or highly flammable substances occur, or structures are in danger of collapsing, their removal is a job for specialized, remote controlled vehicles. But such vehicles are very expensive and take time to arrive at the scene of an accident.

A research consortium led by Fraunhofer IOSB's AST branch has now come up with an alternative and tested it successfully in the field: an autonomy kit known as AKIT that converts universally available construction machinery – common excavators, for example – into unmanned recovery equipment. AKIT is a fast way to add sensors and other components that let vehicles maneuver autonomously in unstructured environments. They also optimally support 3D-based assisted object manipulation and enable adaptive connectivity. All these functions help rescue teams remove hazards quickly. Thanks to its design as a retrofit set, AKIT enables conventional vehicles that are already on site to perform these extraordinary tasks, so there is no need to keep special equipment available around the world.

Our consortium partners in Germany are the Fraunhofer IOSB in Ilmenau and Karlsruhe, Kerntechnische Hilfsdienst GmbH in Eggenstein-Leopoldshafen, Götting KG in Lehrte and SGE-GmbH in Pirna. Associated partners are Claas KGaA mbH in Harsewinkel, Liebherr GmbH in Bischofshofen, and Mannheim's fire brigade and emergency services, all in Germany, along with Palfinger AG in Bergheim, Austria.

Innovative disinfection solutions using UV-C LEDs

Since 2014, Fraunhofer IOSB-AST has been working as part of the Advanced-UV for Life consortium to develop UV LEDs and use them in various real-world applications. We collaborate with tech partners that develop LEDs, such as the

Ferdinand-Braun-Institut für Hochfrequenztechnik in Berlin, to research technical solutions for practical use.

These solutions aim to fully exploit the benefits UV LEDs offer compared with traditional, mercury-based light sources: LEDs feature far higher mechanical stability, can operate at low voltage and offer great flexibility in their arrangement. Plus, their wavelengths can be configured with relative freedom, which makes them suitable for a great many uses. Wavelengths in the UV-C range (240–280 nanometers) are very effective at killing microorganisms because they destroy the DNA in bacteria and viruses.

UV-C LEDs with a wavelength of 265 nanometers improve disinfection quality by up to two orders of magnitude compared with conventional mercury-vapor lamps with the same emissions. This capability makes UV-C LEDs an efficient weapon against multiresistent germs, and they work without chemicals or antibiotics. LEDs are small and emit at high intensity – which makes them ideal for medical uses, such as the targeted disinfection of liquids, surfaces and hard-to-reach areas.

Since LEDs are high-intensity spotlights, when placed in the right configuration they are an efficient way to create complex light geometries. We have a great deal of experience under our belts in designing LED-based UV-C light sources and simulating and optimizing the emission field – experience our customers benefit from every day.

1 *Two machines equipped with the autonomy kit known as AKIT work together in the project's final demonstration.*

2 *The light from these LEDs kills microorganisms reliably.*

IAD | INTERACTIVE ANALYSIS AND DIAGNOSIS

The Interactive Analysis and Diagnosis department develops smart, interactive environments and assistance systems supporting in analysis and diagnosis tasks. Privacy by design approaches ensure the responsible handling of personal data.

Research areas and competences

Our research focuses on decision support systems that enable people to act efficiently even when performing complex tasks involving large amounts of data. These systems are based on artificial intelligence (AI) methods complemented by models that explain the AI proposals. We also develop camera-based components that perceive and understand human activities so that robots and autonomous vehicles can work with humans. We research ways to support collaboration in virtual and extended realities and interaction in these working environments. And, since our work frequently involves processing personal data, our design methods ensure full compliance with data protection laws when developing new technologies.

Applications and products

Our assistance systems and interaction concepts are used in contexts ranging from image-based reconnaissance and surveillance to situation analysis, and from medicine to manufacturing. Currently, we are working on solutions for manufacturing such as digital fault documentation (see facing page) as well as context-based support for assembly workers. Our decision support systems help physicians with diagnosis and therapy, and military personnel involved in surveillance and reconnaissance. One long-term, ongoing project is our Digital Map Table, a system designed to visualize situations and plan tasks. It includes a virtual reality version in which experts can work together in crisis scenarios without being physically present. Thanks to our privacy by design approach, all technologies integrated in our solutions comply with data protection laws.

Infrastructure and lab facilities

We run an Integrated Autonomous Driving Lab featuring a fully connected Audi A1, a polygonal 180° screen, and freely configurable and scriptable simulation software SILAB. Our Agile Innovation Factory Lab features camera-based tools that analyze human activities to assist workers. Examples include tool tracking, detection of people and activity recognition. The Image Exploitation Station of the Future facilitates the integration and testing of new supporting components.

Image Exploitation

RESEARCH GROUPS

- Decision support systems
- Perceptual user interfaces
- Interactive systems
- Identity protection and management

IAD

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QSelect and 4Crypt Video

Quality assurance (QA) is an important part of today's man-ufacturing processes. But many QA tasks, such as surface inspection of pressed metal parts and painted surfaces, cannot yet be fully automated in a cost-efficient manner. This leaves many companies with no alternative to inspection by employ-ees, who scan and visually inspect the surfaces. Yet frequently, quality assurance is limited to mere seconds per component. In these cases, documentation must be kept to an absolute minimum to prevent an stop in production or an imprecise or even incomplete documentation of existing defects.

QSelect is a unique system that enables fast, precise, digital defect documentation directly on each component. It uses an eye-safe laser pointer to intuitively illuminate the location of a defect. A sensor pinpoints the laser's target in real time and the system digitally stores the location of the defect as 3D coordinates. Supplementary documentation can be provided via a freely configurable input menu projected onto the com-ponent, in which various types of defects can be selected. The documented defects are visualized through precise projection onto the component.

The sensor's cameras can also record the rework of the com-ponent for documentation purposes. Whenever the personal data involved in this process needs to be stored, appropriate and effective security and privacy protection mechanisms are essential factors in gaining the trust and acceptance of employees and their representatives. **4Crypt Video** provides a cryptographically secure way to store video footage of critical production work steps, such as safety-critical screws or weld seams. In order to protect workers' privacy, it uses double verification: videos are always encrypted with at least two keys, such as the authorized worker's key plus a works council key, so that video recordings can only be decrypted with the worker's consent. 4Crypt Video uses authentication features from directory services and already includes several different methods (smart card, password, face recognition).

Image Exploitation Station of the Future

Modern reconnaissance and surveillance systems still require humans to interpret the images. The "Image Exploitation Station of the Future" is an experimental system that demon-strates and investigates ways to help the people who perform this task. The system comprises a video surveillance simula-tor based on an open architecture. It makes integrating and testing new supporting components fast and straightforward, so sensor flights and a sensor controller's workstation can be simulated.

Video image interpretation is vital to modern reconnaissance and surveillance systems. Various investigations have shown that a combination of gaze-based interaction and automatic motion detection, object tracking and change detection signif-icantly improves performance while reducing human stress. In order to boost efficiency in surveillance and reconnaissance, we explored options that let a human control a sensor and conduct observation tasks at the same time.

The interaction system we designed reduces perceptive and cognitive stress so that both tasks can be performed simulta-neously. To demonstrate it, we simulated two video sensors (LUNA and pan-tilt) and integrated a joystick, a gamepad and an eye tracker. In addition, we showed that an automatic image interpretation tool can help the sensor controller in detection tasks.

1 *QSelect enables fast, precise, digital defect documentation via an eye-safe laser pointer and an input menu projected onto the component.*

2 *Our Image Exploitation Station of the Future.*

OBJ | OBJECT RECOGNITION

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

Research areas and competences

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

Applications and products

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

Infrastructure and lab facilities

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

RESEARCH GROUPS

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

OBJ

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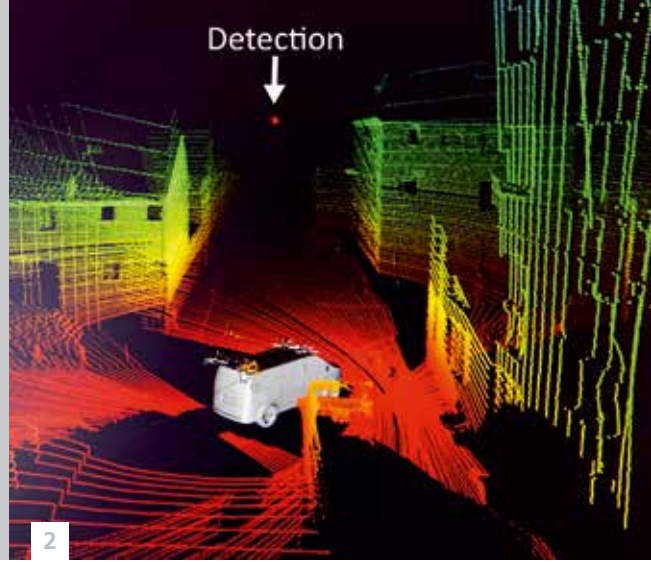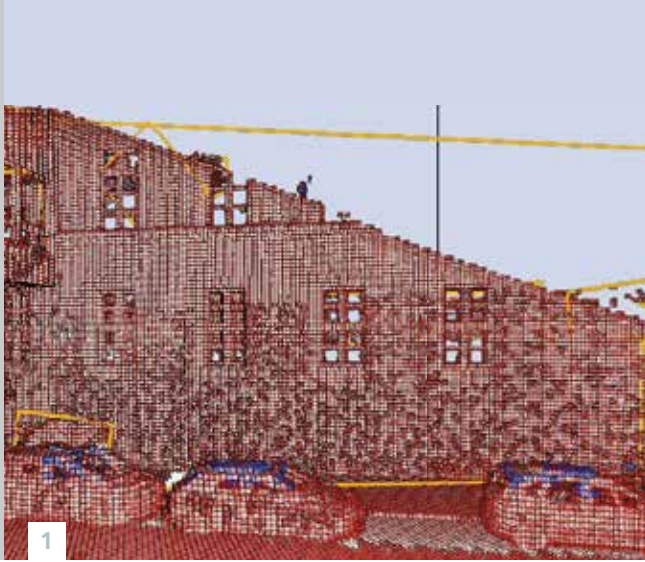
Analyzing change in 3D and assessing risk in urban areas

Mobile laser scanning can capture large-scale urban environments in just a few hours. By taking multiple measurements at different times, changes can be detected automatically, to identify damage to roadside infrastructure or to update 3D city models. Additional research focuses on risk assessment involving special transports as well as the automatic planning of measurement campaigns.

Calibrating the sensor setup involved (intrinsic calibration) while determining the transformation between sensors and vehicle coordinate system (extrinsic calibration) are essential in these applications. In order to avoid having to set up complex calibrations, we are working on methods to derive these transformations directly from measured data. We calculate point clouds based on the individual range measurements of the calibrated sensors, and register them using simultaneous localization and mapping (SLAM). This includes building a pose graph based on navigational data and sensor measurements, which is modified using non-linear optimization to create as accurate a 3D image of the environment as possible. Data originating from several measuring campaigns are coregistered using a similar method.

These coregistered data sets can be used to detect change automatically. The first step is object-based analysis to eliminate moving objects, for example. The actual change detection function then applies a hierarchical occupancy grid, which is adapted to the measurement data in an iterative way that optimizes the ratio between spatial resolution and required memory. One particular advantage to this approach is that it maps unoccupied and unseen parts of the environment in addition to surfaces.

In one of our measuring campaigns, we collected data in and around the Technical University of Munich's city campus and made it available to the public (Data MLS 1 - TUM City Campus).

Lidar-based UAV detection from mobile platforms

In the near future, both military and civilian vehicles will be equipped with a variety of sensors to enhance situational awareness. As part of NATO's SET-260 program entitled "Assessment of EO/IR Technologies for Detection of Small UAVs in an Urban Environment," we are investigating how well commercial mobile lidar system (MLS) sensors can protect military vehicles against UAV attacks. MLS sensors are also used to produce 3D maps of operational areas and provide context information for further analysis.

MODISSA, our experimental platform for hardware evaluation and software development, features four lidar sensors and an EO and an SWIR camera. As it is acquired, the lidar data is synchronized with an inertial navigation system, transferring each 3D range measurement of each of MODISSA's lidar scanners straight to a 3D point in geographic coordinates. This process is known as direct georeferencing. Thus, as MODISSA drives through an area, it automatically generates an accumulated 3D point cloud representing the area's 3D geometry. Figure 2 shows a bird's-eye view of France's CENZUB/Jeoffrecourt military training facility. This 3D point cloud, which was acquired in 32 minutes, is made up of 5 billion 3D points in total.

MODISSA's current UAV detection method uses 360-degree scans from all of its lidar sensors to monitor the vehicle's environment. If a potential threat is detected, the pan-tilt head is pointed in that direction to verify and identify the UAV. This approach was published at the 2019 SPIE conference, Laser Radar Technology and Applications XXIV, DOI: 10.1117/12.2518427, and extensively tested during the CENZUB measurement campaign.

1 *Laser measurements of a street scene, iteratively approximated by an occupancy grid of the type used to detect change automatically.*

2 *Jeoffrecourt city center: screenshot of MODISSA's onboard display with 3D lidar data and real-time detection.*

SZA | SCENE ANALYSIS

The Scene Analysis department's research aims to satisfy the need for rapid interpretation in the fields of intelligence, surveillance and reconnaissance with precise georeference.

Research areas and competences

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

Applications and products

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

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

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

RESEARCH GROUPS

- Image interpretation
- Geo intelligence
- SAR image analysis
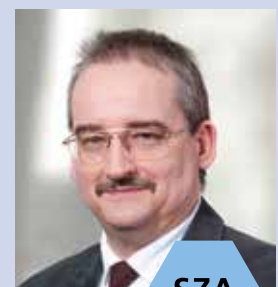
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Scene simulation in thermal infrared

Machine learning with deep artificial neural networks has great potential to improve the way images are processed and understood. When large amounts of training data are available, this can deliver benefits in imaging reconnaissance, protecting critical infrastructure, and in environmental monitoring – as long as the images remain within the spectrum of visible light. Applications that depend on thermal infrared, however, often fall short, since producing labeled training data from infrared images is far less common.

In seeking a workaround for this, we are exploring how far we can push the limits of thermal infrared, or long-wave infrared (LWIR) image simulation. LWIR is highly relevant in military vision systems, since owning the night is a key capability. So virtual simulation systems for training and mission rehearsal should also enable LWIR observation of the scene. This is indeed possible, but in the interest of achieving an acceptable frame rate, physical quality suffers. Physically derived emission simulation does not appear to work with real-time systems.

In order to help training simulators generate more realistic LWIR images at a faster rate, we developed a thermodynamic model that describes 3D objects as layered surfaces. Relevant surface features are reconstructed from remote sensing data derived from aerial images, satellite images and multi- or hyperspectral imaging. A processing pipeline reconstructs geometry and surface materials simultaneously, and converts the results into the layered model. Heat can be transferred between these layers according to physical models. We also added a simple model of atmospheric effects, and more sophisticated features are underway.

The simulation results correlate well with the measurements, which means that using the simulated data as a source for training data to support machine learning classification methods is an option. This, however, is a subject of ongoing research.
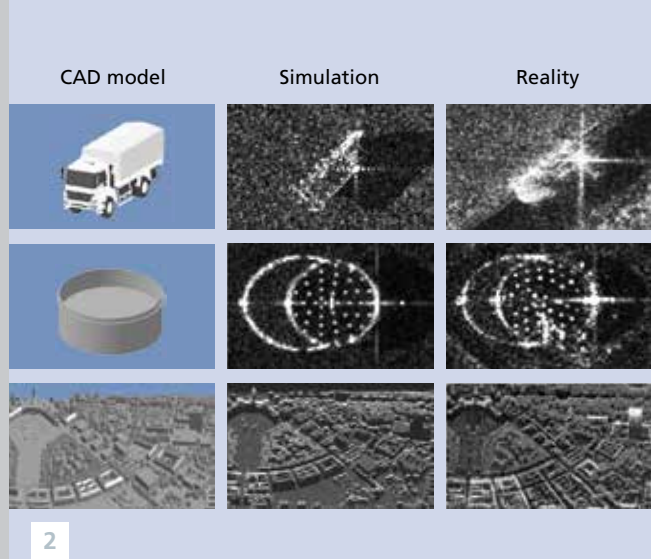
SAR image exploitation supported by SAR simulation

SAR image exploitation comprises signature analysis and feature extraction, as well as change detection and classification based on single images, image pairs and image stacks. Two of the main challenges in this field are interpreting object signatures in SAR data, which is more difficult than in optical data, and the availability of SAR data for functions such as collecting training data for deep learning classification. In these cases, simulated SAR image signatures can provide interpretation aids and a large number of different object signatures.

The core technology of our department's CohRaS® (Coherent Raytracing-based SAR) simulator is an extended ray-tracing approach that simulates both the amplitude and the phase of the returned signal coherently. The simulation uses a 3D model of the object or a whole scene that can contain up to one billion triangles. Performing the simulation requires some SAR sensor parameters and some information about the image creation process in the system being simulated. These include the wavelength, flight path, system resolution, final pixel size and windowing function used in the system. For radiometric correctness, different materials, such as vegetation, asphalt, water and concrete need to be assigned to different parts of the model.

Exemplary applications of SAR simulation include the generation of training data for ATR, the analysis of critical infrastructure, and change detection in complex environments.

1 Simulated thermal infrared image (left) in comparison with a real thermal infrared image taken from a helicopter (right). Data acquired and pre-processed in cooperation with the University of Perth, Melville, Australia.

2 Comparison between CohRaS® simulator's SAR signatures and real SAR sensors: example of an ATR signature (top), of critical infrastructure (center) and a complex urban scene (bottom row).

VID | VIDEO EXPLOITATION SYSTEMS

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

Research areas and competences

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

Applications and products

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

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

Image Exploitation

RESEARCH GROUPS

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

VID

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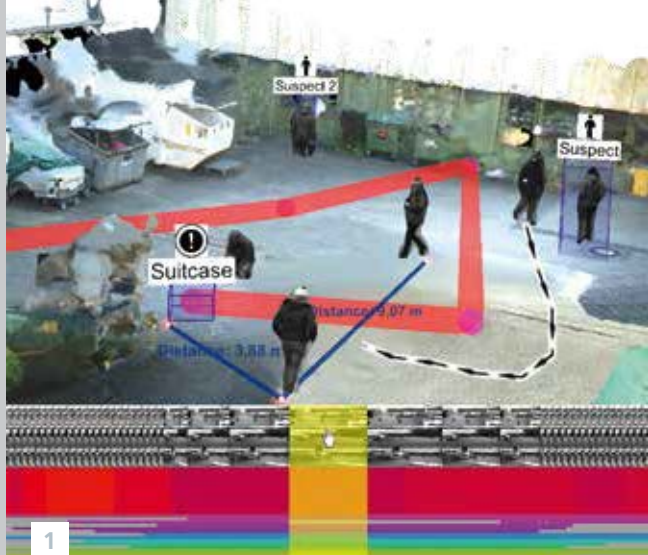
Fusion of images and videos for 4D crime scene investigations

In forensic investigations, images and video data from witnesses and surveillance cameras are used to reconstruct the crime scenes and the course of events. Nowadays, police officers typically view the individual camera recordings one at a time. In cases involving huge amounts of data, the workload is split among several police units, which is very time-consuming.

In an effort to improve and speed up the investigative work, we partnered with the University of Konstanz in a Federal Ministry of Education and Research-funded project known as "Flexible, semi-automatic Analysis System for the Evaluation of Mass Video Data" (FLORIDA) to develop software that calculates the positions of all images (videos) from all cameras, fuses the results and computes a 3D scene. A temporal reconstruction (4D) from all camera perspectives is also calculated and merged with the 3D scene, allowing it to be played back like a single 3D video, viewable from any angle [1]. The advantage here is that all video and image data can be viewed with a temporal reference, giving a clear view of the entire scene/incident.

It is also possible to interact directly with the 4D result in order to view trajectories of particular individuals, for example, or to tag special objects such as suitcases. The user can also go back to the original material at any time, choosing the best view of the current virtual camera perspective. Thanks to a virtual reality (VR) connection, investigators and witnesses can also access the crime scene.

[1]   "Computer Vision meets Visual Analytics: Enabling 4D Crime Scene Investigations from Image and Video Data," 9th Int. Conference on Imaging for Crime Detection and Prevention in London.

Operational products for civil security and defense

ivisX is a software platform for law enforcement agencies. It is designed for criminal investigations involving mass video data. The modular system offers highly efficient processing and analysis capabilities, implementing tools like a map-based overview of all sources, advanced algorithms such as image-based search methods and superresolution, and a handy tool for case-related documentation and preserving evidence.

ABUL is a real-time optimized system for online surveillance and tactical reconnaissance using live images from drones. Tailored to the needs of image interpreters, it boasts a large array of features designed to make their work easier and more efficient (see page 47).

NEST is a versatile suite of products that enable intelligent video monitoring. It consists of activity recognition and crowd monitoring/prediction capabilities and complies with privacy regulations. Potential applications include crime prevention in public spaces, perimeter surveillance, detection of industrial espionage and safety measures for large public events (see page 51).

1 A simulated crime scene, viewable from any angle at any given time (4D), computed from various camera recordings.

2 A developer is testing a variant of the ABUL system for UAV-based image exploitation in real time; it is to be used for tactical reconnaissance.

1

VBV | VARIABLE IMAGE ACQUISITION AND PROCESSING

The Variable Image Acquisition and Processing research group develops methods and systems for automated visual inspection that exploit various kinds of heterogeneous information.

Research areas and competences

We study theoretical and practical issues related to variable image acquisition, i.e. how choices are made during inspections when a single image does not fully capture the features of interest. Our focus areas include modeling image acquisition based on holistic systems theory, the reproducible acquisition of optimal image series, and controlling the variable acquisition parameters – such as illumination, focus, camera position and spectral sensitivity (active vision) – online. Our expertise also extends to methods like ellipsometry and deflectometry. Combined with our capabilities in data fusion, our solutions yield a description quality that is second to none.

Applications and products

We tackle cases that typically cause problems for automated visual inspection systems, such as partially or fully specular (i.e. mirroring) surfaces, transparent objects and thin films on curved surfaces. Our particular skills set can also help solve issues in other fields, like classifying moving objects, providing automated interactive assistance during surgery and generating open, adaptive models of the environment for artificial cognitive systems.

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.

Group manager:
N. N.

1 *Deflectometric measurement. Optical inline quality control of curved specular surfaces has become feasible for the first time thanks to deflectometry procedures developed at Fraunhofer IOSB.*

iosb.fraunhofer.de / VBV

FACTS & FIGURES
2018–2019

2018–19 IN NUMBERS

> 300

committee memberships

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

≈ 70
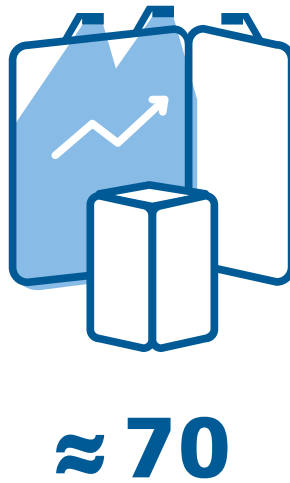
trade fairs and exhibitions

We exhibited our technology at trade fairs such as Hannover Messe and CEBIT as well as specialist conferences and theme days. We also attended 7 career shows.

27
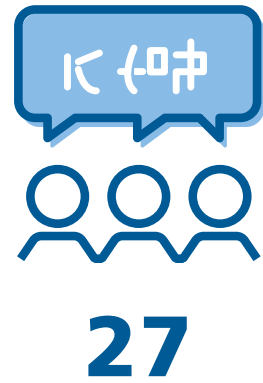
visiting scientists

came and worked with us for different periods of time. Four of them stayed for longer periods, starting from half a year.

> 380

journal and conference papers

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

54
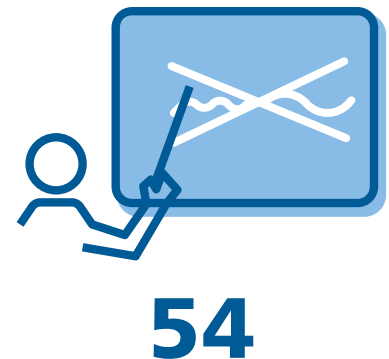
teaching activities

such as lectures, seminars, tutorials and practical courses at different academic institutions were performed by our staff.
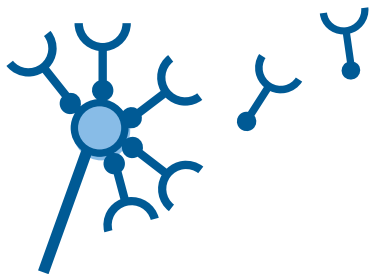
2

spin-offs

are taking technology developed at
Fraunhofer IOSB to the market
(see page 26).
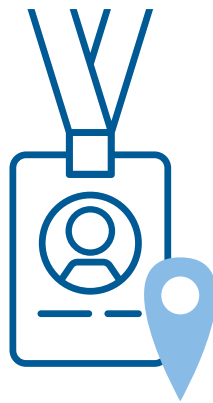
≈ 2,500

participants

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

30

doctorates

Thirty researchers working at
Fraunhofer IOSB passed their doctoral
examinations in 2018 and 2019.

14

patents granted

Applications for a further 33 patents
were filed in 2018 and 2019.
In addition, six product names were
registered as trademarks.

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

iosb.fraunhofer.de/annual-report-2020

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KIT - Institute for Applied Biosciences
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EDITORIAL NOTES

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FÜR ALLE**

10 YEARS OF
FRAUNHOFER IOSB

A young institute with a long history