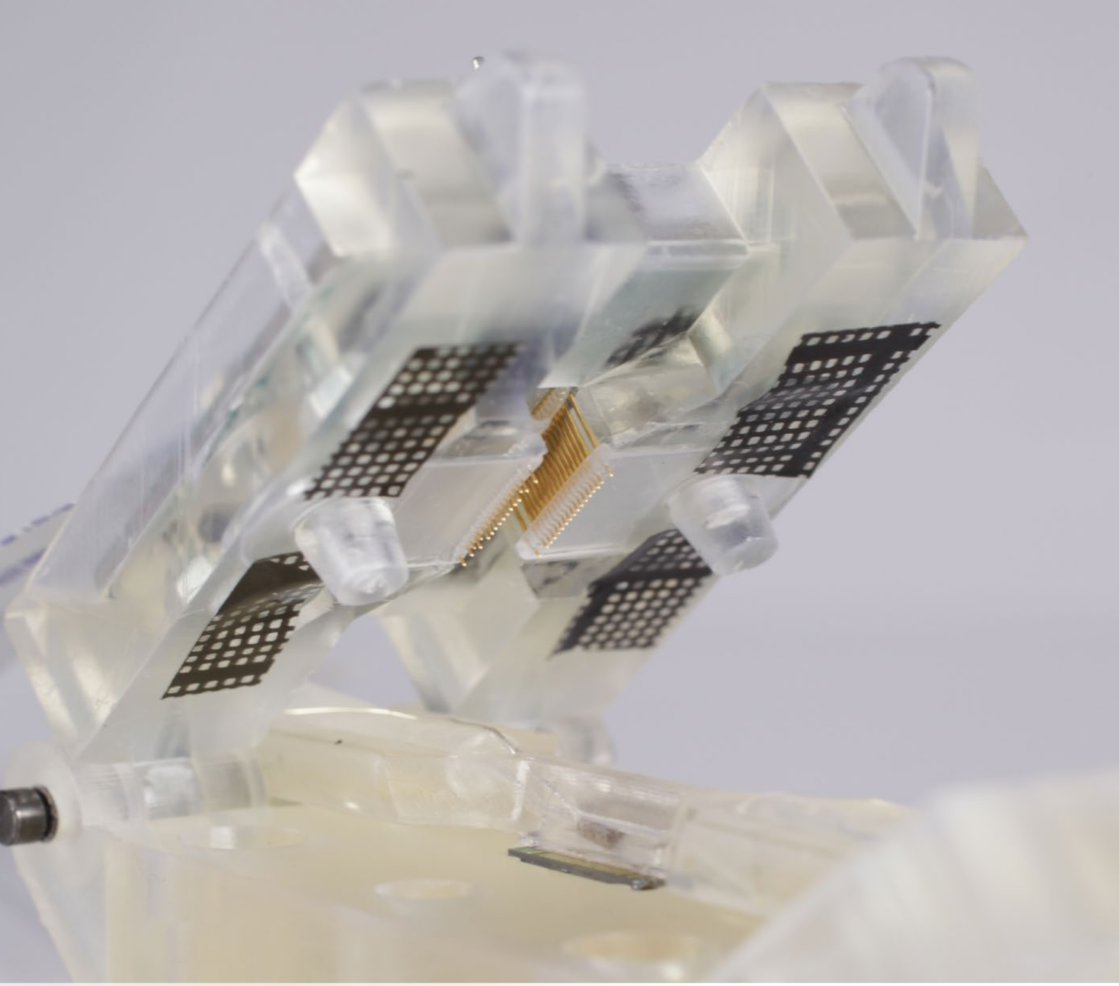

IMMS

ANNUAL REPORT

2025

IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH

Vision, mission, values and strategic foci

Vision

We are **innovative researchers** from **Thüringen** who turn **science** into **applications**. As a leading research partner, we transform ideas into products.

Mission

- **We advance our region.**
  Our goal is to ensure market success for our partners.
- As an application-oriented R&D service provider in Thüringen, we **connect science** and **industry**.
- We create innovative industrial solutions for **intelligent sensor and measurement systems** as well as for **high-precision drive systems**.
  For example, we move atoms and turn networked bioanalytics into pocket size.

Values

- We are a **team on an equal footing**.
- **We take care** of one another and our R&D partners.
- We bring **ideas** to life, that are **ahead of their time**.
- We are inquisitive and always open to new ways of thinking.
- We always have the **application** in mind.
- We aim to be **at the forefront** of innovation, R&D and quality.
- We are **reliable**, compliant and profitable.

Vision

Mission

Values

Research fields

Magnetic **6D direct drives** with nm precision

Integrated **sensor systems**

Smart distributed **measurement and test systems**

Microelectronics

Mechatronics

Embedded Systems

Lead applications

- **Sensor systems for in-vitro diagnostics**
- **nm-measurement and structuring of objects**
- **RFID** sensor technology
- Adaptive **edge AI** systems for industrial applications
- **IoT systems** for cooperative environmental monitoring

Target markets

- Life Sciences
- Automation technology and Industry 4.0
- Environmental monitoring and smart city applications
- Research institutions and ultra-precision mechanical engineering

Competences

WE CONNECT THE DIGITAL ... TO THE ANALOG WORLD.

Leitbild und strategische Schwerpunkte des **IMMS** Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH (IMMS GmbH)
Ehrenbergstraße 27 | 98693 Ilmenau | DEUTSCHLAND | **www.imms.de**

Annual Report

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Frontispiece: A contact unit for preliminary investigations using graphene chips from the University of Jena (FSU Jena) to develop the signal processing electronics for graphene sensors intended for the on-site detection of micropollutants in wastewater. Photograph: IMMS.

www.imms.de/annualreports

Foreword


Martin Eberhardt, Managing Director of IMMS. Photograph: IMMS.

Dear readers,

Research demonstrates its value when scientific findings are transformed into solutions for industry and society. This understanding has been shaping the work of IMMS since its foundation – and has also guided our activities in 2025.

The 2025 financial year was characterised by challenging economic conditions. The economic situation in Thüringen and Germany remained tense. At the same time, institutional funding from Thüringen was reduced. These funds are of great importance for the general operation and preliminary scientific research carried out by IMMS. Closing the resulting funding gap therefore presented a considerable challenge.

The significant increase in industrial contract research has enabled us to bridge the funding gap. Alongside the positive economic performance in 2025, this demonstrates that our research addresses the current challenges in industry and among SMEs. Drawing on our expertise in technology transfer, we work with our partners to develop tailor-made solutions with immediate benefits.

This development confirms that we are on the right track, which we have been following in recent years. We focus our scientific work on topics of high technological and economic relevance, combining scientific excellence with a consistent transfer to practical application. Through numerous new research and development projects, we have been able to further strengthen our three strategic research fields and expand our collaboration with companies and scientific partners.

A particular milestone in 2025 was the launch of the VirtuSen early-career research group, which is funded by Thüringen. It brings together expertise from several research fields at IMMS and opens up new opportunities to further enhance the precision of high-accuracy positioning systems through AI-based virtual sensor technology. In addition, we have made significant progress in many other projects. We present a few examples of these in this annual report.

Scientific success is always the result of teamwork. That is why I am particularly pleased about the awards that young scientists from IMMS received last year in recognition of their research achievements. They are a great example of the high level of commitment and expertise demonstrated by our employees.

The year 2025 also brought personnel changes. New colleagues have now joined our institute, whilst others have moved on to new career paths. I would particularly like to thank my long-standing colleague, the Managing Director Prof. Dr Ralf Sommer, who left IMMS in autumn and is now focusing once again fully on his duties as a university lecturer at Ilmenau TU. I would like to thank him personally for our trusting and constructive collaboration and wish him all the best for the future.

I would like to thank all IMMS employees, our funding bodies, clients and our partners from the academic and business communities. Their trust, ideas and commitment form the basis of our shared success.

I look forward to our journey together and hope you enjoy reading our report.

M. Eberhardt

Martin Eberhardt, Managing Director

www.imms.de/virtusen

www.imms.de/annualreports

Martin Eberhardt, Jessica Völlger, Andreas Rohwer, Dr. Mandy Kandler, Dr. Gabriel Kittler, Prof. Dr. Ralf Sommer, Prof. Dr. rer. nat. Ingolf Voigt, Dr. Sebastian Stark, and Dr. Tobias Sawada at the farewell meeting for Prof. Dr. Ralf Sommer at the Supervisory Board session on 20 November 2025. Photograph: IMMS.

Univ.-Prof. Dr.-Ing. Ralf Sommer leaves IMMS on 30 September 2025

Univ.-Prof. Dr.-Ing. Ralf Sommer took over the scientific management of IMMS in September 2006 from its founding professor, Dr Gerd Scarbata, after stints at the Technical Universities of Braunschweig and Kaiserslautern, the Fraunhofer Institute for Industrial Mathematics, and Infineon Technologies AG.

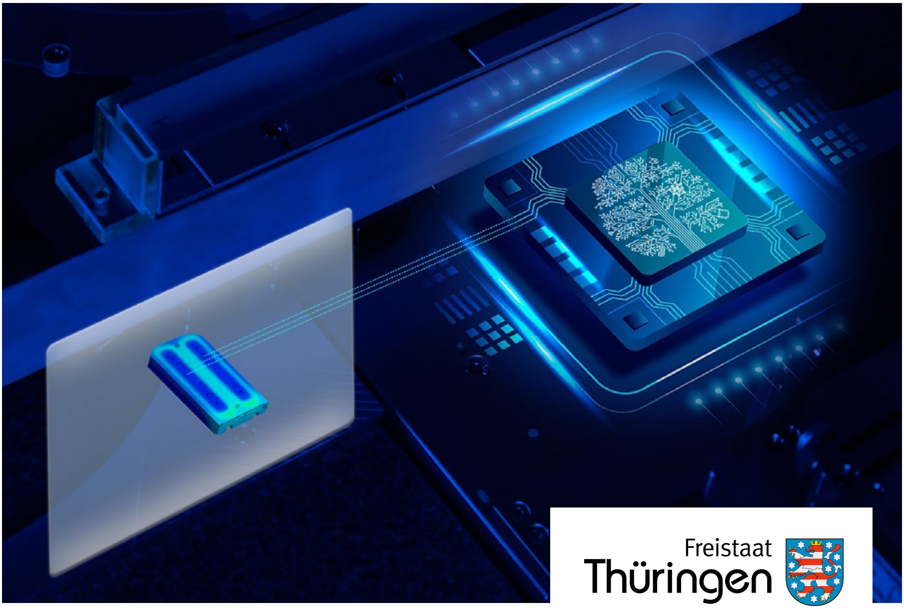
The supervisory board and owners thank Univ.-Prof. Dr.-Ing. Ralf Sommer for his commitment and the work he has done at IMMS.

The appointment procedure for filling the position of scientific director of IMMS in conjunction with a joint appointment to a university professorship (W3) in ‘Integrated Circuits for Sensor Systems’ at the Faculty of Electrical Engineering and Information Technology at Technische Universität Ilmenau has not yet been completed.

IMMS will therefore be represented by commercial director Dipl.-Kfm. Martin Eberhardt until a new scientific director is appointed.

From 1 October 2025, Univ.-Prof. Dr.-Ing. Ralf Sommer will be available via the Electronic Circuits and Systems department at the Faculty of Electrical Engineering and Information Technology at Technische Universität Ilmenau.

For the supervisory board: Dr. Sebastian Stark, Chairman of the supervisory board



VirtuSen aims to use a small number of physical sensors to generate virtual sensors using AI methods. Photographs/graphics: IMMS/Pixabay (u_8t3emw1yia).

Internal research group VirtuSen* launched – virtual sensors and AI for detecting and compensating disturbances in complex mechatronic systems

Monitoring sensors are often limited

In the monitoring of machines or other complex mechatronic systems, the objective extends beyond tracking the current state of the system and addressing topics such as predictive maintenance. It also involves using the acquired information to develop new system solutions with improved performance characteristics. In addition to system parameters, disturbance factors such as temperature, humidity, and mechanical stresses, as well as their spatial distribution, play an important role. However, due to functional and spatial constraints, physical sensors often cannot be installed at all measurement locations required for a comprehensive assessment. Consequently, in practice, disturbance variables are typically measured at only a limited number of locations using a restricted set of sensors. As a result, the implementation of effective countermeasures is also limited.

www.imms.de/virtusen

AI-based virtual sensors expand the range of possible solutions

In the VirtuSen research group, IMMS is working to significantly improve the monitoring of systems using AI-based virtual sensors. AI approaches make it possible to model complex system behaviour based on a small number of input variables. VirtuSen aims to leverage this capability to assess spatial distribution using limited data from real sensors. The goal is to predict the behaviour of the entire system by adding AI-based virtual sensors for the disturbance variables, in order to subsequently identify and implement targeted countermeasures.

Application for effectively improving the precision of positioning systems

This is particularly relevant for high-precision positioning and measurement systems. Even minor environmental influences, such as temperature fluctuations and the resulting thermal expansion of materials, can significantly impair the achievable accuracy in the sub-nanometre range. For high-precision applications, it is especially important to understand not only the magnitude but also the spatial distribution of disturbance factors. The results from VirtuSen are intended to enable a more accurate quantification of environmental influences on such systems, thereby providing a basis for reducing their impact on positioning accuracy in future applications.

Three doctoral dissertations on model-based thermal characterisation, physics-based AI models, and the generalisation capability of AI models

The project will be carried out through close collaboration between IMMS and Technische Universität Ilmenau until the end of 2027. IMMS will provide supervision, infrastructure, and financial support, while Prof. Husung and Prof. Römer from Ilmenau TU will offer scientific guidance and academic supervision. The research activities are divided into three doctoral topics, each addressing a complementary aspect of thermal disturbance prediction and AI-based virtual sensor technology for high-precision systems.

The VirtuSen team at the test rig for the NPS6D100 drive in the IMMS laboratory: Amin Suaad, Ahmed Rahat, Ina Naujokat, and Parastoo Salimitari (f.l.t.r.). Photograph: IMMS.

Ina Naujokat completed her master's degree in mechanical engineering in March 2025 and has since been working at IMMS on the "VirtuSen" project while pursuing her Ph.D. under the supervision of Prof. Husung. Her research focuses on physics-based thermal characterisation, numerical simulation approaches, and model reduction methods for precision systems.

Ahmed Rahat joined the project as a research associate in July 2025 after completing his studies in Computer Science and Data Science and is pursuing his PhD under the supervision of Prof. Römer. His work focuses on physics-informed neural networks (PINNs) for precision improvement of nanopositioning systems, in particular for the prediction of temperature fields and virtual sensing based on sparse measurement data.

Amin Suaad earned his B.Sc. in Electrical Engineering and Electronics and later completed a master's degree in Data Science. He is currently pursuing his Ph.D. under the supervision of Prof. Römer and has been working as a research assistant at IMMS since January 2025. His research focuses on the generalisation and transferability of AI-based virtual sensors to various systems. A particular focus is on the prediction of environmental disturbances under limited measurement conditions.

www.imms.de/virtusen

In addition to coordinating all research activities, Dr.-Ing. Parastoo Salimitari contributes to investigations of material effects on thermal behaviour, with a focus on mineral casting structures as an alternative to granite bases in precision systems. Her work supports the experimental and simulation-based activities across the individual doctoral research topics and forms a common foundation for the development and validation of the proposed methods.

Outlook

The objective of IMMS is to utilise the results obtained in VirtuSen to enhance the precision of the positioning systems studied within IMMS, thereby addressing future industrial demands. In the longer term, the aim is to transfer these approaches to a broad range of machines, metrology applications, and mechatronic systems, significantly improving both their performance and cost efficiency.

Furthermore, the developed methods are expected to support the research and development of novel industrial automation solutions, enabling more precise analysis, as well as improved control and regulation of processes and systems.

www.imms.de/virtusen

Working hand in hand with Technische Universität Ilmenau

Being an affiliated institute of Ilmenau University of Technology (TU), IMMS benefits from networking with the university while the TU benefits from the Institute's close relations with industry. In 2025, IMMS again worked on scientific projects and issues with numerous departments in the fields of electrical engineering and information technology, mechanical engineering, computer science and automation as well as mathematics. In parallel, IMMS is strongly networked with industry. To develop internationally successful innovations for health, the environment and industry, IMMS is integrated into regional and national innovation networks as well as industrial clusters. The use and bundling of technological competences and the development of joint market strategies provide valuable practical impetus for the research activities of the Institute and the Ilmenau TU.

Selection of joint projects

ProQuaOpt*: Optimising the injection moulding process with AI for greater efficiency

To harness AI methods for automated productivity and quality optimisation of the injection moulding process, a product-process-quality control loop was developed consisting of a controlled system on the injection moulding machine, a measuring element for quality inspection and an AI-based controller. This enables reactions to changing environmental conditions and continuous optimisation of the process in terms of resource efficiency. IMMS developed the AI-based controller, which helps to optimise the process inline and autonomously – when adjusting the machine and reacting to faults.

www.imms.de/proquaopt

Read the specialist article in this report

Waldmonitor*: Robust communications solutions and energy self-sufficient sensors

To counter the consequences of climate change, the Waldmonitor (forest monitor) project is developing a sensor system that continuously collects information on young trees without the need for foresters to be on site. A stationary overall system as a pilot installation is evaluating various optical and classic sensor principles. The results will be incorporated into an optimal selection of sensor systems for a customised monitoring system, which will later also be able to be used on mobile platforms. IMMS contributes adaptive energy self-sufficient sensor systems and the data connection to open up the monitoring of location factors in the forest environment and to ensure a continuous flow of data from the study areas in the forest to a central evaluation.

www.imms.de/waldmonitor

The NanoFab* RTG: High-speed fabrication with nanometre precision

Until 2026, 13 doctoral students, including one at IMMS, are working on solutions for tip- and laser-based 3D nanofabrication in extended macroscopic workspaces in phase 3 of the NanoFab research training group 2182 funded by the DFG. They are supervised by professors and scientific staff of Ilmenau TU and IMMS under the direction of the Institute for Process Measurement and Sensor Technology of the Faculty of Mechanical Engineering. IMMS is developing solutions for a drive system that will enable multi-axis highly dynamic machining of objects with nanometre precision.

› *Integrated sensor systems*
› *Distributed measurement + test systems*
› *nm-precise 6D direct drives*
› Contents
* Funding

www.imms.de/nanofab

IMMS as "Smart Sensor Systems Model Factory" in the "Mittelstand-Digital Zentrum lmenau" (SME Digital Centre Ilmenau)*

As the "Smart Sensor Systems Model Factory", IMMS provides impetus for the introduction of Industry 4.0 technology for the improvement of machinery and processes. An example of what this means is retrofitting machinery and equipment with wireless and networked sensors so that data can be obtained and processed which will underpin new diagnostic, maintenance and service concepts. Combining open-source software with universal electronics platforms for components that are compatible to Industry 4.0 is a powerful means of achieving real-time-capable innovation fast and affordably.

www.imms.de/md

InSignA* high-performance centre

The aim of the "InSignA" high-performance centre in Ilmenau is to strengthen the regional economy by accelerating technology transfer. Regional value creation networks in the future-oriented transfer areas of signal analysis and assistance systems in production, energy supply and robotics are to be developed and established. To this end, Fraunhofer institutions in and around Ilmenau, the research profile lines at Ilmenau TU and other research institutions are pooling their expertise. In the iHUB project of the German Land of Thüringen, the partners support start-ups and spin-offs in the field of intelligent signal analysis and assistance systems.

www.imms.de/insigna

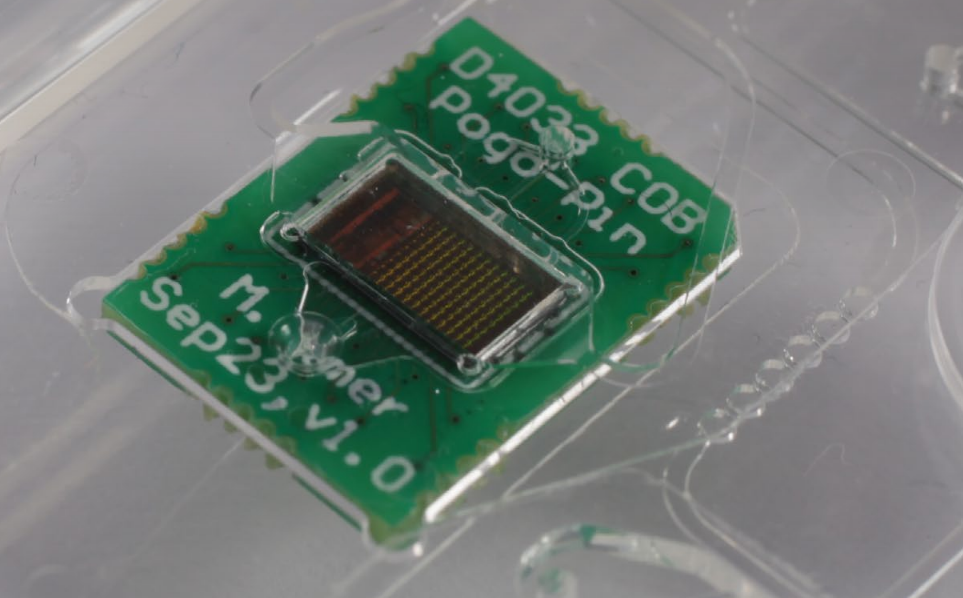
More on iHub in this report

Joint encouragement of young academics

IMMS not only complements teaching at Ilmenau TU with extensive practical offers. In addition, Prof. Sommer and Prof. Töpfer are involved with courses in basic education and in the master's programme. IMMS promotes the motivation and training of students through its practical and industry-related offers, among other things, through numerous topics for internships.

VOICES
FROM INDUSTRY AND ACADEMIA

All references: **www.imms.de/ref**



Chip developments such as those in the 'FluoResYst' project – which enable direct DNA spotting followed by fluorescence detection – often highlight the potential for further joint technology transfer projects. More information is available in the following reference statements.

The **FluoResYst** project was funded by the Federal Ministry of Research, Technology and Space (BMFTR) within the photonics research funding framework under the reference **13N15807**.

With funding from the:

Federal Ministry of Research, Technology and Space

Dr. Christof Steiner, DITABIS AG

“At DITABIS, we see ourselves as partners on an equal footing – for our customers, we are the OEM partner when it comes to medical technology, diagnostics and life sciences. Our teams bring together expertise in mechanics, electronics, software and regulatory affairs – all under one roof. From the initial feasibility assessment right through to series production in accordance with ISO 13485, we support our customers as true co-developers: with an agile, collaborative approach and decades of experience.

Dr. Christof Steiner, Head of Business Development, DITABIS Digital Biomedical Imaging Systems AG. Photograph: DITABIS.

I first came across IMMS as part of our joint BMFTR project, ‘FluoResYst’. Whilst IMMS is developing the chip for direct DNA spotting followed by fluorescence detection, we at DITABIS are responsible for integrating the system into a complete device. Working with Benjamin Saft and Eric Schäfer, it quickly became clear that IMMS can do far more than ‘just’ chip development – particularly in the fields of photonics and sensor technology. This is evident in both the versatile staff and the exceptionally well-equipped laboratory and measurement technology.

www.imms.de/fluoresyst

With this impression in mind, it was an easy decision for us to bring IMMS on board to develop an optical assembly for one of our high-volume production devices. The result: 15 prototypes in which the hardware, firmware, optics and mechanics work together perfectly – and which have even exceeded our high expectations.

www.imms.de/rd

What we particularly liked: The IMMS team integrated quickly and flexibly into our network of DITABIS developers and external partners – bringing plenty of ideas and a genuine team spirit.

Following this thoroughly positive experience, we would be happy to work with IMMS again at any time – even though we are over 300 kilometres apart.”

www.imms.de/ref

DITABIS

www.ditabis.de

Andrea Kulik, Managing Director / CEO of FRIZ Biochem GmbH.

Photograph: FRIZ Biochem GmbH.

Andrea Kulik, FRIZ Biochem GmbH

"We develop innovative molecular diagnostic solutions for standardised (high-throughput) use in the laboratory, as well as for direct use at the point of care. Our products are characterised by high sensitivity, short turnaround times and user-friendly workflows.

We have appointed IMMS as our development partner for our CYCLE®-Dx platform, which enables multiparametric, rapid, highly sensitive and fully automated PCR analyses to be conducted outside a laboratory, directly at the point of care. The CMOS biochip, developed jointly with IMMS to detect DNA hybridisation on electrochemical sensor arrays, will in future be integrated into the analysis unit of our PoC platform.

In previous research projects, we laid the technological foundations and validated the performance of our CMOS biochip approaches. The aim of the subsequent collaboration was to work with IMMS to translate these findings into a commercially viable product. We were particularly impressed by their proven expertise in the development of analog and digital integrated circuits and systems, especially in the field of CMOS biosensors.

www.imms.de/biosensors

The IMMS team contributed extensive expertise in the CMOS technology used, as well as in specialised manufacturing processes, including microsystems techniques for integrating precious-metal electrodes directly onto the chip, and TSV technologies for bond-wire-free integration into our analysis unit. The process steps required for this were provided by our long-standing partner X-FAB and seamlessly integrated into the overall system.

We were particularly impressed by how IMMS was able to take a holistic approach to the interface between biochemical applications and electronic signal processing. This enabled our biochemical and technical requirements to be precisely translated into microelectronic concepts and implemented in a space-efficient manner.

In addition to technological excellence, the collaboration was characterised at all times by agility, transparency and reliability. Coordination was swift and solution-oriented, and all milestones were met on schedule and to a high standard.

We would like to express our sincere thanks for the professional and trusting partnership and look forward to continuing to work together in future innovation projects."

www.frizbiochem.de

www.imms.de/ivd

www.imms.de/ref


Roland Haag, ASIC Design Team Leader at Leuze electronic GmbH + Co. KG. Photo: Constanze Lutz-Haag.

"As a medium-sized family-run business based in the greater Stuttgart area, right at the foot of Teck Castle, we are actively shaping the future of Industry 4.0 with innovative products and solutions. Over 60 years of experience have made us a leading expert in innovative and efficient sensor and safety solutions for automation technology. Our high-tech portfolio covers a wide range of sensors and automation solutions: from switching and measuring sensors, through identification systems, to data transmission technologies and image processing systems.

IMMS has shown itself to be an extremely valuable partner in all matters relating to research and development. Particular mention must be made of the proven expertise of our colleagues in the technological fields that are central to our work. They not only support us in evaluating innovative circuit concepts, but also make a significant contribution to the development of cutting-edge integrated circuits (ICs).

Through a joint workshop with IMMS, we gained valuable insights into the properties of state-of-the-art CMOS-based optoelectronic components and circuits. Particularly noteworthy are the in-depth explanations of how they work, as well as the practical application examples, which have provided us with lasting inspiration. We also value our collaboration with IMMS on the layout synthesis of our digital circuit components, which has consistently been characterised by great commitment, agility and an exceptionally collegial working style.

www.imms.de/asics

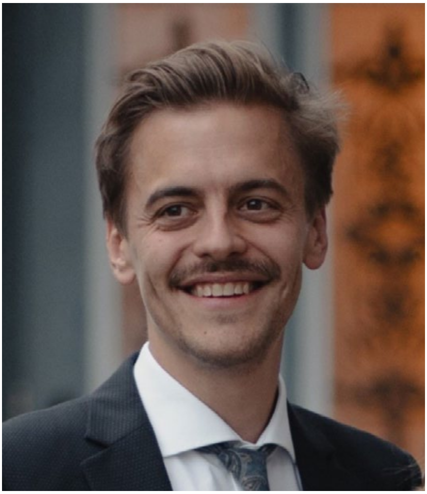
Throughout our collaboration, IMMS has been an extremely reliable and competent partner. We were impressed by the high quality of the results and the constructive, goal-oriented collaboration. We are therefore looking forward to working with IMMS again on future development projects."

www.imms.de/ref

Leuze

www.leuze.com

Markus Øverland, attocube systems



Markus Øverland, Senior Manager R&D Actuators & Sensors, attocube systems GmbH. Photograph: private source.

“In the field of Motion & Sensing, attocube develops nanometre-precise positioning and sensor systems for industrial applications in high-tech markets such as semiconductor and quantum technology.

In collaboration with IMMS, we were able to successfully integrate our ultra-precise IDS3010 laser interferometer into an ultra-precise voice-coil positioning system developed by IMMS.

The aim was to demonstrate reproducible positioning down to the picometre range under vacuum conditions, thereby illustrating a potential use case based on the current state of research. At the same time, we were able to successfully verify, through external testing, both the performance of our sensor system and its ease of integration.

The IMMS’s Mechatronics division contributed its extensive expertise in control engineering and ultra-precise positioning. Of particular note is the control logic developed, which enables positioning performance below the conventional sensor noise limit. At the same time, the Rapid Control Prototyping framework employed by IMMS allowed for the rapid and flexible integration of our sensor into the overall system and kept the time to result very short.

Our collaboration with IMMS was always very professional, straightforward and characterised by open and efficient communication. Together, we were able to demonstrate that, by combining our systems and expertise, reproducible closed-loop positioning down to the double-digit picometre range is possible under vacuum conditions. The project has not only confirmed the performance of our interferometer in an innovative use case, but has also resulted in a joint white paper as a tangible outcome of our successful collaboration. We look forward to implementing further joint projects in the field of high-precision sensors and actuators for applications in the sub-nanometre range in the future.”

www.attocube.com

attocube
WITTENSTEIN group

www.imms.de/nmdrives

www.imms.de/mechatronics

Read the white paper

Marcus Cramer, Managing Director of KHW Kunststoff- und Holzverarbeitungswerk GmbH in Geschwenda. Photograph: KHW.

Marcus Cramer, KHW Kunststoff- und Holzverarbeitungswerk GmbH

“We are the world’s leading manufacturer of plastic snow sleds – from simple children’s sleds to innovative high-tech products. With decades of experience as an efficient and competent partner in plastics processing, we guarantee excellent injection moulding capacity and quality for a wide variety of products, components and requirements. In addition to a wide range of garden products, we also manufacture cool boxes, dustbins and plastic pallets. We achieve this not only through state-of-the-art machinery and certified processes, but also through the continuous development of our materials, products and procedures. For example, under our KHW – ECO-2MIND label, we are increasingly focusing on bio-based and biodegradable plastics, prioritising energy-efficient processes, and many of our products are already made from recycled plastics. For this wide range of products and materials, it is essential to adjust the machinery flexibly to the optimal parameters for each application to achieve high-quality results in the shortest possible production cycles.

As part of our joint ProQuaOpt project, IMMS has developed AI methods to automatically optimise productivity and quality in injection moulding. The IMMS team quickly gained a deep understanding of injection moulding processes and has impressively demonstrated the potential that AI offers for optimising our processes and improving resource efficiency. With the AI-based optimisation developed by IMMS, which utilises a surrogate model and an NSGA-II algorithm, the injection moulding machine can be optimally adjusted according to the input parameters without compromising quality, and it is also possible to respond to external disturbances. During trial operations on one of our production lines, we have thus succeeded in significantly reducing cycle times whilst avoiding defects.

With its expertise in AI algorithms in an industrial context, IMMS made a vital contribution to the project's success. The IMMS team worked proactively and with a clear focus on the objectives. At the same time, it responded flexibly to changes as the project progressed. The collaboration was smooth and collegial, and IMMS always kept the overall objective of all five partners in mind and provided support. We look forward to the possibility of further joint projects in the future, in which we can build on this successful collaboration."

www.khw-geschwenda.de

Made in Germany

www.imms.de/proquaopt

Read the specialist article in this report

www.imms.de/ref

ENCOURAGEMENT OF YOUNG ACADEMICS

All information on our study-related offers:

www.imms.de/students

› Integrated sensor systems
› Distributed measurement + test systems
› nm-precise 6D direct drives
› Contents
* Funding

Encouragement of young academics

It is one of our highest priorities to bring on the new blood in science. We are active in pursuit of this goal, inspiring and supporting undergraduate and master's students of the engineering sciences in particular by supervising internships and dissertations for BSc and MSc. The fact that we network so closely with industry provides the new generation of scientists with the opportunity to work on subjects of practical relevance where the results really matter. Thus, we impart theoretic in-depth knowledge of methods for an early combination with a practical implementation in applications. For fundamental education purposes various lectures and seminars are hold by IMMS staff at Ilmenau TU. Moreover, we offer training courses and guided tours of the establishment. School pupils, too, are given insight into our work by means of events and internships or by having their coursework supervised by professionals of the institute.

For example, we accompany offers for the Summer University of the Ilmenau TU and regularly organise BarCamps on the topic of electronic design automation. Students also take part in these interactive and open research meetings. Our internationally competitive industrial-standard infrastructure for design support and laboratory technology for electronic and mechatronic systems is also available for student research work.

www.imms.de/barcamp

Participation in career fairs

In 2025, IMMS took part in four careers fairs at Technische Universität Ilmenau, Erfurt University of Applied Sciences, Coburg University of Applied Sciences and Technische Universität Chemnitz. Students from disciplines such as electrical engineering,

www.imms.de/students

In 2025, IMMS provided information at three other universities – as it has done here at Erfurt University of Applied Sciences – on work placements and final-year projects, as well as on opportunities to join the institute.

Photograph: IMMS.


Master's students from the "Optoelectronic Systems" course taught by Prof. Dr Alexander Richter in the Department of Electrical Engineering and Information Technology at Ernst Abbe University of Applied Sciences, Jena, were given a tour around IMMS Erfurt. Photograph: IMMS.

mechatronics, computer science and related degree programmes found out about opportunities for work placements, final-year projects and part-time work, as well as other ways to start their careers at the institute. This long-term, practice-oriented training programme, which runs alongside students' studies and features challenging topics, individual supervision and industrial-standard equipment, prepares students for a career start in industry and applied research. The aim is to strengthen companies in the region by supporting the next generation of talent at IMMS. The institute has also highlighted its high-quality and dedicated support for young talent through a variety of other initiatives.

www.imms.de/students

Support for a course at the Ernst Abbe University of Applied Sciences, Jena

The Master's students on the 'Optoelectronic Systems' course taught by Prof. Dr Alexander Richter in the Department of Electrical Engineering and Information Technology at Ernst Abbe University of Applied Sciences, Jena, were also supervised at IMMS. Throughout the summer semester, they worked on small design projects in the field of optoelectronics in collaboration with IMMS, for example on miniaturised optical components or optoelectronic receivers and their properties. This was complemented by a visit to IMMS in Erfurt, which provided insights into current research projects and included a tour of the laboratory featuring a wide range of measurement technology for microelectronic solutions.

https://www.linkedin.com/feed/update/urn:li:activity:7333125118602235906

Participants of the Conference of Medical Technology Student Unions (KOMET) on their study trip to Erfurt-South-East, visiting X-FAB, the CiS Institute for Microsensors, and IMMS. Photograph: IMMS.

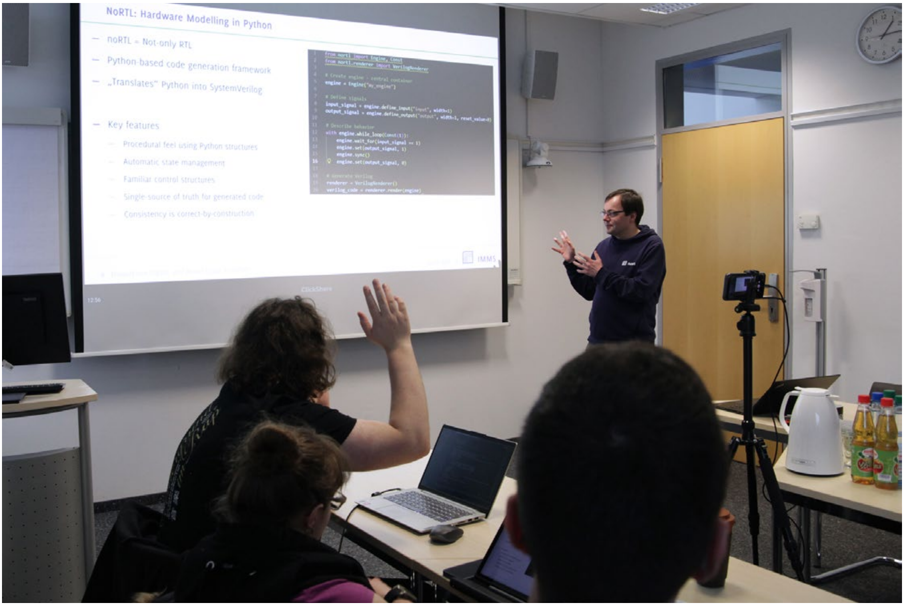
Visit by the Conference of Medical Technology Student Unions (KOMET) to IMMS

In May 2025, the Conference of Medical Technology Student Unions (KOMET) attended IMMS in Erfurt. The 30 students from various technical universities across the German-speaking world – including Darmstadt TU, the University of Erlangen-Nürnberg, Graz TU, Ilmenau TU, the Jena University of Applied Sciences and Lübeck University of Applied Sciences – spent four days at Ilmenau TU with the aim of continuously improving medical technology degree programmes – amongst other things, through networking with industry. Excursions such as the one in May 2025 to X-FAB, the CiS Institute for Microsensor Technology and IMMS – organised by the FiZ Research and Industry Centre Erfurt e.V. – are a regular feature of every KOMET event. At IMMS, numerous practical examples clearly demonstrated just how closely the medical technology degree programme is linked to chip design. There were several demonstrators on display for integrated sensor systems for in-vitro diagnostics, drawn from current projects. All these solutions also incorporate student projects, which are intensively supervised at IMMS.

In August 2025, Martin Grabmann gave a lecture entitled “Before It Hits the Chip: A Gentle Introduction to Mixed-Signal IC Verification” at the International Summer School on Microelectronics (ISSOM25) at Leibniz University Hannover. Photograph: Leibniz Universität Hannover.

Lecture at the International Summer School on Microelectronics at Leibniz University Hannover

In August 2025, we took part in the International Summer School on Microelectronics (ISSOM25) at Leibniz University Hannover, where Martin Grabmann gave a lecture entitled “Before It Hits the Chip: A Gentle Introduction to Mixed-Signal IC Verification”, and provided information about our topic offerings and student support in the accompanying exhibition. ISSOM 2025 was attended by students keen to explore the entire life cycle of a chip, from concept to the final circuit. Contributions were made by our partners Leibniz University Hannover, Braunschweig TU, RWTH Aachen, TU Wien and FMD – Forschungsfabrik Mikroelektronik Deutschland (German Research Centre for Microelectronics), with support from the Chipdesign Germany network, which is funded by the BMFTR.



During the 2025/2026 winter semester, Dr.-Ing. Georg Gläser taught the lecture 'Design of Digital and Mixed-Signal Systems' at IMMS in Ilmenau. Exam results are recognised by Ilmenau TU. Photograph: IMMS.

Lecture on chip design at IMMS

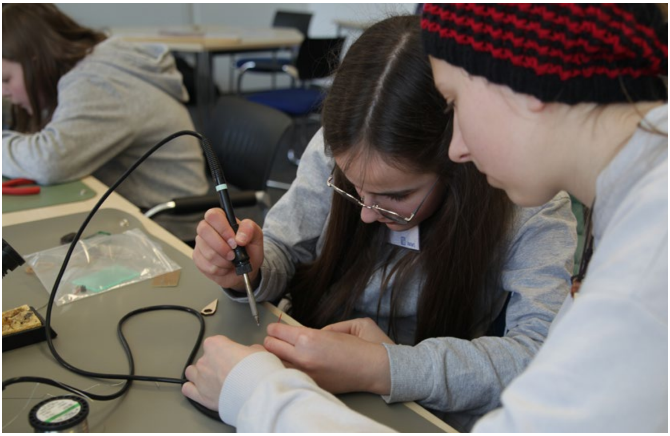
www.imms.de/students

In the winter semester of 2025, Dr.-Ing. Georg Gläser launched the lecture course 'Design of Digital and Mixed-Signal Systems' for students at Technische Universität Ilmenau, with the aim of fostering expertise in the development of integrated circuits and thereby specifically strengthening Thüringen's semiconductor ecosystem. The courses held at IMMS Ilmenau enable students to acquire in-depth knowledge of the systematic design of digital and mixed-signal systems at the chip level, and to learn how to break down complex system functions into modular, implementable functional blocks and estimate their characteristics – such as area and latency – at an early stage. Central to this is the analysis of real-world chip architectures and typical design errors, which enables a practical understanding of proven design patterns and strategic decisions in mixed-signal design. The course finished with a design project, including documentation and a short final presentation, which counted as the assessment.

A call for the edaBarCamp was issued once again for September 2025. Hosted by IBM Böblingen, with support from edacentrum, IMMS and the DLR Institute for Systems Engineering for Future Mobility, the event featured nine sessions over two days, during which contributions from 50 participants representing Bosch, Infineon Technologies, the Fraunhofer Society, LUBIS EDA, Intrinex GmbH, Technische Universität München, the Universities of Stuttgart and Tübingen and many others were lively discussed. In the open BarCamp format, questions were asked and answers found on topics ranging from verification challenges, AI applications, the open-source mindset, EDA flows, current trends in microelectronics, AI and robotics, right through to system performance evaluation and COCOTB-based verification, whilst exploring ideas for future innovations in design automation.

The series was started in 2016 by edacentrum, OFFIS and IMMS to enable regular interactive, open researcher meetings – for undergraduate and postgraduate students, professors, experts from both industry and public service and, indeed, for anybody with an interest in EDA (electronic design automation), microelectronics and system design. The edaBarCamp series has its origin in the interdisciplinary PhD seminars of the ANCONA project.

https://edabarcamp.de



Supervised soldering work during Girls' Day 2025 at IMMS.

Photograph: IMMS.

Girls'Day 2025

Fraunhofer IDMT, IMMS and TU Ilmenau gave girls from grade 5 onwards their first insights into science, research and development during Girls' Day in April 2025. As part of this nationwide career and study guidance initiative, girls learn about professions or fields of study in which the proportion of women is below 40 per cent, such as the natural sciences, engineering and computer science. At IMMS, 13 girls from grades 5 and 7 took advantage of this opportunity to discover what vibrations can do and how they can be made visible, to write programme code on the Open Roberta platform using the Calliope mini system, to solve tricky questions – both small and large – in the puzzle corner, and to solder their own torches. The pupils from the grammar schools in Ilmenau, Arnstadt and Suhl, and from the Ilmenau 'Franz von Assisi' reform school, thoroughly enjoyed themselves and were looked after with equal enthusiasm by a team of two female engineers and a female mathematician from IMMS, supported by student volunteers.

Open Roberta workshop as part of the programme to support gifted pupils in the Ilm district

As part of the Ilm District's programme to support gifted pupils, IMMS organised an afternoon at Ziolkowski Primary School for 18 fourth-grade pupils via the Open Roberta Coding Hub – a collaborative partnership between the Technische Universität Ilmenau, Fraunhofer IDMT and IMMS. Following a brief introduction, the children were able to write their own programme code using the Open Roberta platform, upload it to the Calliope board and then set the calli:bot mobile robot in motion.

Dr.-Ing. Alexander Hofmann, scientist at IMMS

„Combining technology and biochemistry to create innovative solutions that improve people's lives continues to motivate my work, even after 14 years at IMMS. IMMS provided me with the opportunity to explore the emerging field of CMOS biochip technology. Its highly interdisciplinary nature led me through various areas of science and industry, including (micro)electronics, biochemistry, materials and electronic technologies, systems engineering, process development, and validation, ultimately culminating in the successful completion of my doctoral degree. Throughout this journey, the consistently supportive, constructive, and collegial working environment at IMMS helped me overcome challenging periods and complex tasks alike.

www.imms.de/biosensors

Following this extensive period of professional development and qualification, IMMS has also enabled me to pursue new objectives and an additional personally meaningful aspect of my work: transferring newly researched and developed CMOS biochips into practical applications and industrial exploitation. Current industrial projects – some of them international in scope – across various life science sectors clearly demonstrate both the demand for such solutions and their growth potential beyond academically driven research. At the same time, these activities allow me to further strengthen my skills in communication, project management, project

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Dr.-Ing. Alexander Hofmann, specialist in electrochemical CMOS sensors in the microelectronics department at IMMS.

Photograph: IMMS.

preparation, and business development. Close collaboration with industrial partners provides valuable insights into application-specific needs and challenges, for which the IMMS team continuously develops tailored solutions. Moreover, this interface with industry forms the basis for future research activities at IMMS, generating new value and innovation for life science applications.

While my initial focus at IMMS was primarily on the development and optimisation of biosensing analog integrated circuits, my work has gradually evolved toward a holistic perspective on CMOS biochip systems. Today, I even have the opportunity to help build, organise, and shape entire value chains in this field, which once again broadens my horizons and gives me great satisfaction. In terms of diversity, scope, freedom, and support for personal and professional growth, IMMS offers an ideal environment for individual development and fulfillment.“

Manuel Jirsak, M.Sc., scientist at IMMS

“In the summer of 2022, I had my first opportunity to get involved at IMMS through a three-month internship whilst I was studying. This was followed by several months as a student assistant, culminating in my Bachelor’s thesis in the spring of 2023, during which I was also able to write and publish my first paper. During my Master’s degree, IMMS gave me the opportunity to work part-time alongside my studies. Furthermore, IMMS supported me with my Master’s thesis, which I was able to complete to great success in the summer of 2025, thanks in large part to the excellent

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Manuel Jirsak, M.Sc., specialist in design methodology in the microelectronics department at IMMS.

Photograph: IMMS.

internal supervision. I am particularly grateful for the flexible working hours scheme and the opportunity to occasionally work from home. This makes even the more stressful periods easier to manage.

Since I started my career, I have mainly been working in the field of electronic design automation (EDA). My aim has always been to support digital circuit development, both in terms of circuit verification and optimisation with regard to area, speed and power consumption. The development process for these circuits is highly complex and extensive, so any form of automation is a welcome assistance for circuit designers. When I first started out in research and development, this was simply a small piece of software that modified circuits so that they consumed less power when certain parts of the circuit were inactive. As time went on, I was able to implement various additional mechanisms that have great potential for application in digital circuit development or are the subject of current research. The scope of application ranges from features that simplify verification to complex algorithms for circuit optimisation. I have packaged all of this in a user-friendly, handy Python programme. Its source code is freely available online to maximise its benefits for both academia and industry.

Publication at www.imms.de

„Netlist Carpentry“ software at GitHub

Right from day one, I have enjoyed the pleasant working atmosphere and the consistently friendly and constructive interactions amongst my colleagues. Through regular conversations with my colleagues, I have already been able to benefit greatly from their experience, ranging from theoretical background knowledge to practical tips and tricks. The research topics are grounded in real life and relevant to practice, which is a particular source of motivation for me. As a team member at IMMS, I am therefore actively helping to bridge the gap between research and application. This brings me great pleasure every single day. I really enjoy working at IMMS!”

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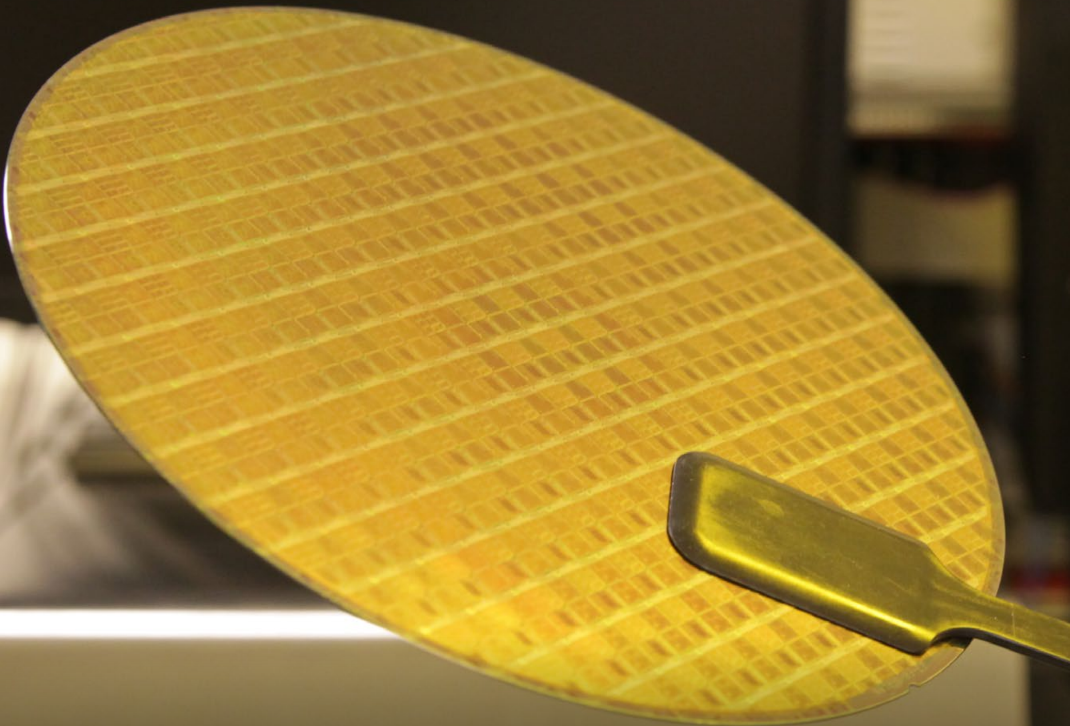
RESEARCH FIELD

INTEGRATED SENSOR SYSTEMS



PANDIA is developing innovative integrated sensor technology for spectroradiometers to enable significantly better and more efficient analysis of light for numerous applications in the future. Photograph: IMMS.

Funded by the European Union

Freistaat Thüringen

The interdisciplinary partnership for innovative spectroradiometers from Thüringen (**PANDIA**) is supported by the funding programme of the German Land of Thüringen for the promotion of research, technology and innovation (RTI) as the research and development initiative Thüringen Verbund under the joint project number **1004537**, the IMMS topic “Development and research of line sensor ICs for spectroradiometers” under the reference 2025 VFE 0027.

Research field: **Integrated sensor systems**

In the research field "Integrated sensor systems", we investigate miniaturised systems manufactured in semiconductor technology consisting of microelectronic and/or microelectromechanical components for sensors applications, as well as methods to design these highly complex systems efficiently and safely.

Integrated sensor systems connect the analog with the digital world:

Electrical, mechanical and optical parameters can be directly detected, amplified, digitised and transmitted on these silicon chips with an edge length of just a few millimetres. They are mobile, energy-efficient, precise and powerful and therefore represent the key technology for the Internet-of-Things (IoT). Functionalised chip surfaces can be used to measure additional physical as well as chemical and biological parameters. With integrated sensor systems, structural sizes in the µm range can be achieved and thus properties can also be detected on a molecular scale, such as in the sequencing of DNA.

www.imms.de/sensor-ics

Goal: new applications through functional integration and miniaturisation

We aim to pioneer new applications through functional integration and miniaturisation. In the field of **CMOS-based biosensors**, we are researching CMOS-integrated transducers and their interaction with biological receptors. In the area of **ULP sensor systems**, we are reducing the energy demand of integrated sensor systems through intelligent power management and ultra-low power (ULP) circuit technology. Our intensive research into **AI-based design and test automation** enables our partners and us to automate the development of highly complex integrated sensor systems and make them safer.

www.imms.de/biosensors

www.imms.de/ulp

www.imms.de/aidesigntest

Research with commercial technology for industrial exploitation

The goal of our research is always industrial exploitation. We therefore focus on system design with commercial semiconductor technology. Large quantities can be used here to achieve competitive and cost-effective solutions. In addition, IP protection and trustworthiness are strengthened.

Integrated sensor systems are incorporated into solutions for all target markets of IMMS. In the lead applications of **sensor systems for in-vitro diagnostics** and **RFID sensor technology**, we focus on the use of integrated sensor systems in life sciences as well as in automation technology and Industry 4.0 target markets.

www.imms.de/ivd

PANDIA* project launch – innovative spectroradiometers for better analysis of light

With a kick-off meeting on 23 September 2025 in Erfurt, the project partners IMMS, JETI Technische Instrumente GmbH and X-FAB Global Services GmbH began work on the three-year joint project 'PANDIA – Interdisciplinary Partnership for Innovative Spectroradiometers from Thuringia', which was launched in September. The project, which is funded by the German Land of Thüringen and co-financed by the European Union, brings together expertise in optics and photonics from Jena with expertise in microelectronics and sensor technology from Erfurt. The aim is to develop new generations of spectroradiometers with higher sensitivity, shorter measurement times and a larger dynamic range to analyse light much better and more efficiently for numerous applications.

www.imms.de/pandia

Spectroradiometers – universal tools with limits

Spectroradiometers are indispensable tools in many scientific and industrial applications that require precise analysis of the spectral properties of light. They are used in a wide variety of fields around the world – from HDR display and projector manufacturing and the lighting industry to photovoltaics, materials science and environmental technology, the food industry, pharmaceutical quality control, medical research and diagnostics.

However, in terms of speed, measurement accuracy, dynamic range and stability, the global state of the art does not meet the economic and technical requirements in some applications, for example because the measurements hold up production for too long, environmental influences such as high temperatures can distort the results, and new reference measurements and recalibrations then cause further delays. The reason for this is that the devices have so far relied on purchased detectors. In addition, components such as mechanical shutters and, for more demanding measurements, cooled sensors or optical assemblies are used, which hinder compact integration into small measuring devices.

Novel integrated sensor technology for spectroradiometers

In PANDIA, the partners are therefore developing application-specific line sensor chips for the first time. These include two new sensor concepts that will be integrated into the microelectronic chips. On the one hand, photodiode-based line sensors with integrated electronic dark reference are being developed. These will replace solutions with the conventional mechanical shutter, halving the measurement time and increasing robustness. Secondly, the development of SPAD-based line sensors will use single-photon avalanche diodes (SPADs), which detect individual photons and can therefore detect even extremely weak light sources.

In addition, both sensor concepts feature integrated analog-to-digital converters and temperature sensors, which will increase measurement accuracy and facilitate system integration.

X-FAB, JETI and IMMS pool expertise

The project combines the strengths of three Thuringian partners: IMMS coordinates the project, will develop the microelectronic sensor chips from circuit diagrams, layout and simulation to commissioning, and will assist with integration into the spectroradiometers. JETI will contribute its experience in the development and marketing of spectroradiometers and integrate the new sensors into demonstrators for suitability tests and into laboratory samples that will be evaluated under real-life conditions in application-oriented scenarios. X-FAB will provide the XS018 semiconductor technology and supply optimised photodiodes and SPADs. This close cooperation will close the regional value chain from semiconductor manufacturing to research to the end product.

Contribution to technological sovereignty

PANDIA will make the German Land of Thüringen less dependent on non-European suppliers for critical sensor components. The new generation of spectroradiometers will be faster, more sensitive and more robust, thereby strengthening the international competitiveness of the partners involved. At the same time, the project will contribute to the economic development of the region by linking the innovative strength of Thüringen's two key industries, optics/photonics and microelectronics.

www.imms.de/pandia

Representatives of the project partners X-FAB, JETI and IMMS of the PANDIA project, which was launched in September 2025, at the kick-off meeting on 23 September 2025 in Erfurt. Photograph: IMMS.

From right to left: Prof. Dr.-Ing. Ralf Sommer (supervisor, head of the Electronic Circuits and Systems Group at the Faculty of Electrical Engineering and Information Technology, Technsche Universität Ilmenau, and, until September 2025, scientific director of IMMS), Alexander Hofmann (specialist in CMOS biosensors at IMMS) and Prof. Dr.-Ing. Karsten Seidl (examiner, University of Duisburg-Essen) after the defence on 23 April 2025 of Alexander Hofmann's doctoral thesis "CMOS biochip system for the optical detection and quantification of analytes". Photograph: IMMS.

Semiconductor-based biosensors for point-of-care diagnostics – a viable alternative to laboratory testing

Doctoral thesis on an optical sensor system for in vitro diagnostics defended

www.imms.de/biosensors

On 23 April 2025, Alexander Hofmann, a specialist in CMOS biosensors at IMMS, successfully defended his doctoral thesis, 'CMOS Biochip System for the Optical Detection and Quantification of Analytes', at Technische Universität Ilmenau. The research, conducted at IMMS, demonstrates how the advantages of rapid mobile tests can be combined with the high accuracy of established laboratory diagnostics. At the heart of the system is an optoelectronic CMOS chip based on standardised semiconductor technology, which can be manufactured cost-effectively and scaleably. The system was validated using two bioanalytical methods. Both validations demonstrate that CMOS-based solutions enable the precise and digital detection of molecular and protein-based analytes. This achieves measurement performance previously only possible in specialised laboratories. This research provides the foundation for the development of sensor systems for in vitro-diagnostics, through which IMMS is exploring applications for personalised, decentralised health monitoring using rapid electronic tests.

"We have been presented with a highly interdisciplinary, outstanding doctoral thesis with significant practical relevance," says Prof. Karsten Seidl, PhD (Eng.), reviewer of the thesis and Professor of Medical Technology at the Faculty of Engineering at the University of Duisburg-Essen. The thesis combines CMOS-based biosensor technology and optoelectronics with applications for molecular tests and immunoassays. And that is crucial when speed is important but the results need to be as accurate as those obtained in a laboratory, Karsten Seidl continues.

High-precision diagnostic systems for detecting infections and diseases are complex, large and expensive. They are primarily used in centralised laboratories by trained specialists. Results often involve waiting and transportation times of several days.

But when rapid test results are essential – such as in emergency situations in an ambulance – point-of-care tests are an option. These rapid tests have the advantage of being easy to use on site, compact and inexpensive. However, for many applications, they lack sufficient sensitivity or they are not digitised – or both.

www.imms.de/ivd

"With his doctoral thesis, Alexander Hofmann has laid the foundation for an innovative class of point-of-care diagnostic systems that combine laboratory-level precision with the compactness and cost-effectiveness of rapid electronic tests. His work is an impressive example of how CMOS technology and bioanalytical methods can be integrated to form a powerful platform for decentralised health monitoring," explains Prof. Dr.-Ing. Ralf Sommer, his supervisor and, at that time, scientific director of IMMS, as well as head of the Electronic Circuits and Systems group at the Faculty of Electrical Engineering and Information Technology at Technische Universität Ilmenau. "The developed concepts open up new prospects for rapid electronic tests – ranging from molecular detection of infectious diseases and personalised health checks to tests for allergens, nutrients or contaminants in food and drinking water. By combining optical and ion-sensitive detection mechanisms, an even wider range of bioanalytical applications can be covered in future without relying on laboratory equipment."

Alexander Hofmann with an optoelectronic CMOS biochip on a cartridge and an associated test system for research relating to his doctoral thesis “CMOS Biochip System for the Optical Detection and Quantification of Analytes”.

Photograph: IMMS.

CMOS biochip system for the optical detection and quantification of analytes

www.imms.de/biosensors

The doctoral thesis demonstrates that light absorption measurements using a newly developed optoelectronic CMOS biochip system can combine the advantages of precise laboratory techniques with those of rapid tests. “In the investigated CMOS biochip system, samples are applied directly to an optical sensor chip and the biochemical reaction is measured without any distance between the sample and the light detector,” explains Alexander Hofmann. “Our partners have developed protocols – in other words, recipes – for the functionalisation of the chip surface required for this.” This allows the detection of biochemical reactions where the intensity of light absorption is dependent on the concentration of the bound analyte. “These changes can then be measured optoelectronically as differences in brightness.”

In his thesis, he investigated how the distance between samples or analytes to be measured and the detector affect the maximum achievable sensitivity. He discussed the advantages and disadvantages compared with conventional optical approaches, and compared contact sensing and contact imaging approaches with regard to their achievable sensitivity. He also developed a concept for modelling the optical, biochemical and electronic components of the CMOS biochip system. This enables the estimation of achievable performance parameters such as sensitivity, signal resolution, signal-to-noise ratio, dynamic range, concentration measurement range and detection limit.

Bioanalytical validation

The system was validated using two selected bioanalytical methods. Firstly, DNA was detected for the first time on CMOS biochips by means of light-absorption measurements without the need for biomarkers. Synthetic target DNA was employed for this purpose. Through DNA hybridisation, the targets were localised on the photodiodes of the developed CMOS biochip system and detected with high sensitivity. The measurement series carried out as part of this work indicate that such a system .has the potential to provide not only highly accurate but also PCR-free molecular detection.

Secondly, an immunological assay targeting prostate-specific antigen (PSA) demonstrated for the first time that the developed CMOS biochip system surpasses the performance of the rapid-test standard LFA and reaches, and in certain aspects exceeds, the performance level of the laboratory standard ELISA.

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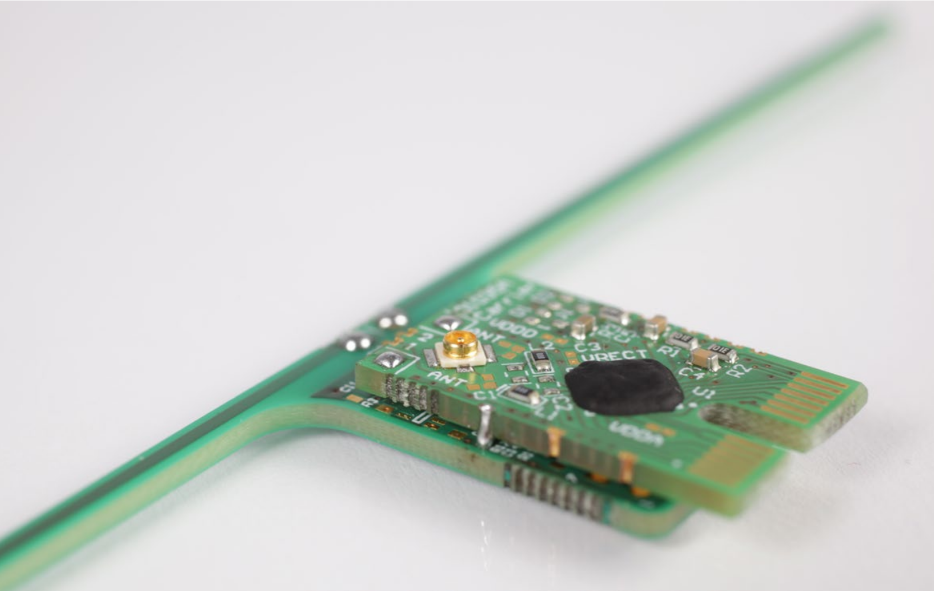
Research at IMMS into sensor systems for in-vitro diagnostics

“With his doctoral thesis, Alexander Hofmann has not only produced an outstanding piece of academic work, but has also played a decisive role – both in terms of content and methodology – in shaping the development of further bioelectronic diagnostic systems at IMMS. His contribution to expanding bioanalytical detection technologies to include ISFET-based, ion-sensitive methods is particularly valuable – an important step that usefully complements the optical platforms established at IMMS. Through his interdisciplinary approach, his project leadership and his innovative spirit, he has significantly advanced the development of technological expertise in this strategically important field of research,” summarises Prof. Sommer.

www.imms.de/ivd

The research activities of IMMS in the field of CMOS-based biosensors thus extend to optical analysis methods, such as those using single-photon detectors (SPADs), and to charge-based analyses, such as those using ion-sensitive field-effect transistors (ISFETs). Together with partners, IMMS is investigating how these can be used to digitise further physical, chemical and biological parameters. In addition, IMMS is working on combining integrated circuits with other diagnostic technologies, such as microfluidic lab-on-chip systems.



Test setup for preliminary investigations into UHF RFID sensor transponder ICs with innovative memory technology for smart sensor applications in logistics. Photograph: IMMS.

Launch of the NeAIxt* project: UHF RFID sensor transponder ICs for smart sensor technology

Expansion of IMMS UHF RFID sensor technology for smart logistics applications

IMMS is expanding its ultra-high-frequency RFID sensor technology with a novel, particularly energy-efficient storage technology. The aim is to provide intelligent identification and sensor solutions for industry and logistics that are energy-efficient and open up new application possibilities, such as monitoring cold chains or material integrity. In the project, IMMS is supplying a powerful UHF RFID transponder IC, which is being integrated into a Bluetooth Low Energy (BLE)-based sensor node by project partner microsensys. This sensor node is to be activated via existing RFID infrastructures and then perform data processing and communications – an approach that significantly increases energy efficiency and extends battery life.

www.imms.de/rfid

www.imms.de/neaixt

Challenges with moving objects

Our partner microsensys plans to use the sensor nodes in fast-moving objects that are to be read by stationary infrastructure, for example in monitoring production resources. In such dynamic scenarios, long ranges and particularly fast response times are crucial for reliable wake-up behaviour to ensure fast and accurate data acquisition.

Innovative storage technology as a technological basis

The basis for this is the proven UHF transponder technology of IMMS from the StorAIge and HoLoDEC projects. It will be supplemented by a novel FeRAM memory IP from project partner X-FAB, which will also be developed in the NeAIxt project. This memory solution is characterised by extremely low energy consumption and will play a central role in the new chip design. In addition, IMMS will explore further approaches to accelerate the wake-up process and evaluate them in prototypes. The result will be a forward-looking solution for digital logistics.

With funding from the:

Chips JU

Co-funded by the European Union

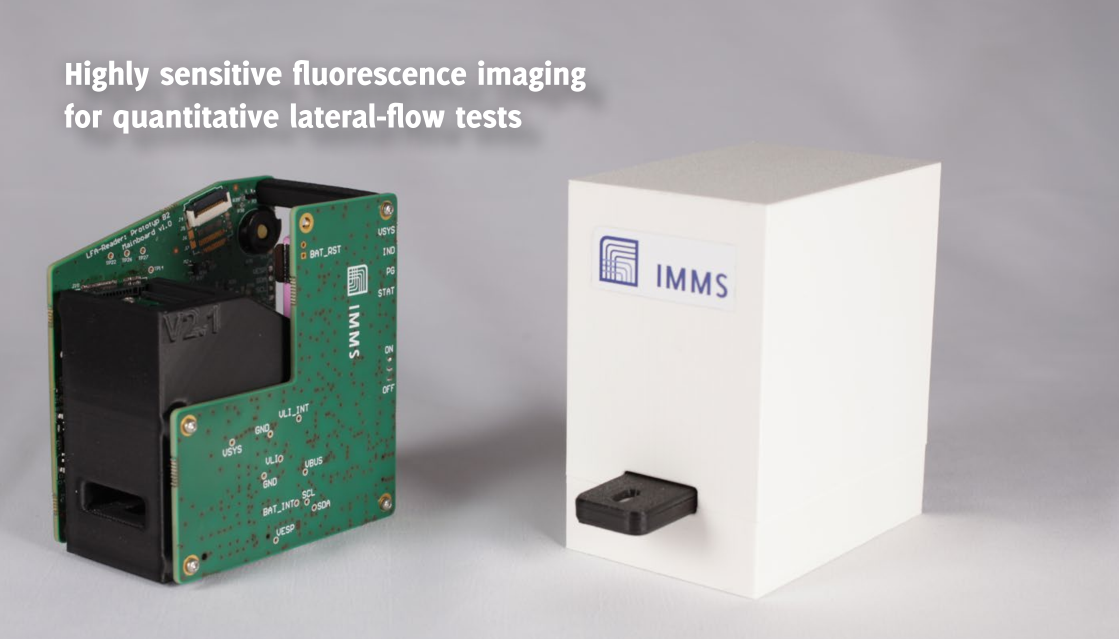
Federal Ministry of Research, Technology and Space

Freistaat Thüringen

Ministerium für Wirtschaft, Landwirtschaft und Ländlichen Raum

www.imms.de/neaixt

Highly sensitive fluorescence imaging for quantitative lateral-flow tests



IMMS developed a CMOS image sensor with optimised lock-in pixel technology and a compact fluorescence reader for the quantitative evaluation of lateral-flow assays in point-of-care applications. Photograph: IMMS.

Motivation and overview: quantitative lateral-flow tests using fluorescent markers

www.imms.de/ivd

Lateral-flow assay (LFA) test strips have become an established diagnostic platform due to their low cost and ease of use. Conventional test strips based on gold nanoparticles as colourimetric labels generally provide only qualitative yes/no results and quickly reach their limits in terms of sensitivity and quantification.

However, many medical applications require quantitative information on biomarker concentrations, for example for the early detection of myocardial infarction using troponin or for monitoring infectious and inflammatory diseases. Conventional rapid tests are often insufficient when diagnostically relevant biomarkers are present at very low concentrations.

Fluorescent labels such as europium(III) complexes enable significantly more sensitive measurements compared to gold nanoparticles and open up new possibilities for quantitative point-of-care diagnostics with sensitivities approaching those of laboratory-based methods. As a result, time-critical diagnostic decisions can be made directly at the point of care without the need to send samples to centralised

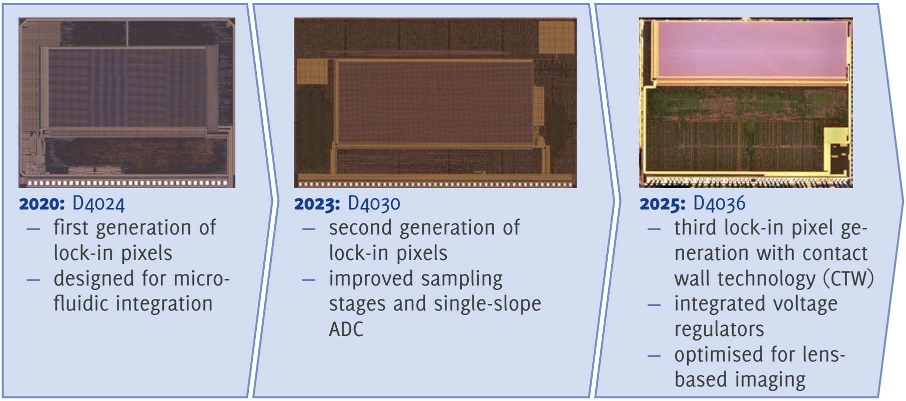


Figure 1: Evolution of the lock-in pixel sensors developed at IMMS. Chip photos/Graphic: IMMS.

laboratories. This substantially reduces the time to result and can be particularly beneficial in emergency situations or resource-limited settings. Furthermore, fluorescence-based approaches offer the prospect of multiplex testing, allowing multiple biomarkers to be analysed simultaneously.

www.imms.de/ivd

Within the TIRELESS research group, IMMS combined the results and expertise gained from the predecessor projects MEDIKIT, Ovutinin, and SensInt to develop an optimised reader for fluorescence-based LFA tests as well as a new generation of lock-in pixel sensors. The main objectives were to further improve the detection limit while simultaneously simplifying and miniaturising the overall system.

www.imms.de/trf

The core of the system developed at IMMS is a dedicated CMOS image sensor for time-resolved fluorescence imaging. In this approach, the fluorescent label is first excited by pulsed UV light. The actual measurement is performed only after the

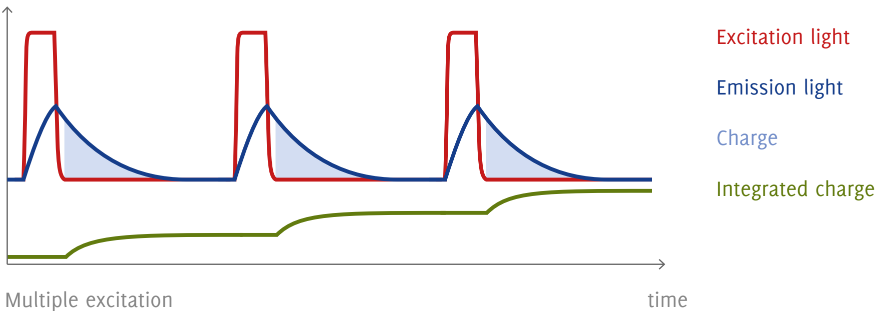


Figure 2: Principle of lock-in pixel technology. After the excitation light has decayed, the emitted fluorescence signal is measured until it also decays. This process can be repeated multiple times, allowing the fluorescence signal to be accumulated cycle by cycle and thereby increasing sensitivity. As a result, separation by optical filters is not required. Graphic: IMMS.

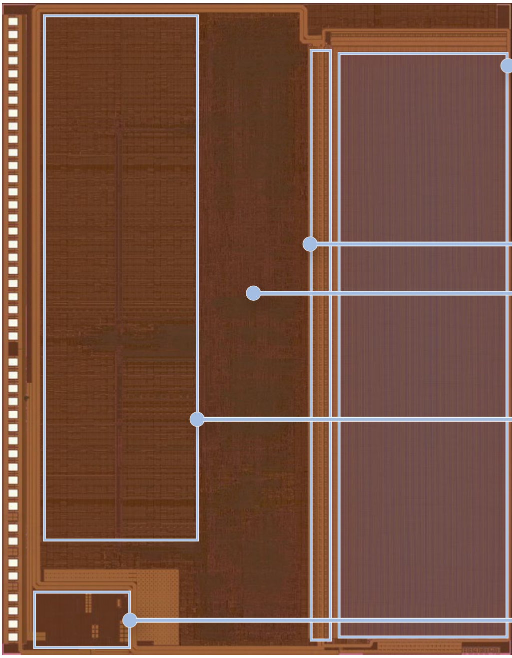
Video explaining the lock-in principle: https://youtu.be/pEXdMNZZkPA

excitation light has decayed. Using the lock-in principle, the significantly weaker fluorescence signal can be electronically separated from the excitation light and accumulated over many excitation cycles, enabling quantitative detection of extremely low analyte concentrations.

Challenges: excitation light, weak fluorescence signals, and interference effects

Time-resolved fluorescence measurements place stringent requirements on the suppression of optical excitation light. Although signal acquisition starts only after the UV excitation has been switched off, even small amounts of parasitic light within the sensor pixels can significantly limit measurement dynamic range and achievable sensitivity. This becomes particularly critical when detecting weak fluorescence signals accumulated over many measurement cycles.

A key challenge is that not only the photodiode itself is photosensitive, but also surrounding structures within the pixel can unintentionally collect light. One of these structures is the floating diffusion (FD) node. The FD node serves as the central charge storage node of the pixel, receiving the charge generated by the photodiode before it is read out. If light reaches this node directly or indirectly, parasitic charge signals are generated, which can distort the fluorescence measurement. This limits the effectiveness of electronic excitation-light suppression and ultimately constrains the achievable sensitivity of the overall system.



Features of the TIRELESS chip:

Lock-in pixels with pinned photodiodes
– Pixel size: 12.5 µm x 12.5 µm
– 100 rows x 350 columns
– Optically isolated floating-diffusion (FD) node for improved excitation-light suppression

Row-wise single-slope ADC

Freely configurable image acquisition via programmable sequencer
– Simple interface connectivity via I²C and QSPI

Integrated SRAM image memory for one full frame

Power-supply system with integrated voltage regulators

– XS018 CMOS technology
– Total chip size: 3800 µm x 4860 µm

Figure 3: Micrograph: IMMS.

New lock-in pixel generation with contact-wall technology

At IMMS, two variants of a new image sensor chip were developed. Both feature an image array of 100 x 350 pixels with a pixel pitch of 12.5 µm x 12.5 µm and are fabricated in X-FAB's 180 nm XS018 CMOS technology. The lock-in pixel architecture enables direct electronic suppression of excitation light at the pixel level while accumulating the significantly weaker fluorescence signal over many excitation cycles.

www.imms.de/aidesigntest

Pixel values are digitised column-wise using integrated single-slope ADCs. In addition, the sensor incorporates on-chip image memory and programmable control logic for image acquisition.

One of the sensor variants employs X-FAB's Contact Wall Technology (CTW) for the first time to provide additional optical shielding of parasitically photosensitive pixel regions. The objective of this new pixel architecture was to further improve suppression of fluorescence excitation light and thereby increase sensitivity in time-resolved fluorescence measurements.

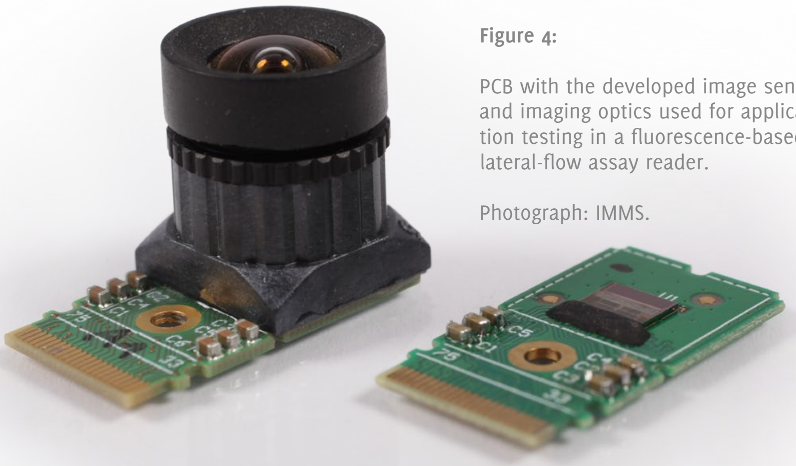


Figure 4:

PCB with the developed image sensor and imaging optics used for application testing in a fluorescence-based lateral-flow assay reader.

Photograph: IMMS.

The chip was also optimised with respect to system integration and external circuitry. The goal was to reduce the number of required external components and establish the basis for compact and cost-efficient reader systems, continuing the integration strategy pursued in previous projects.

To achieve this, voltage regulators and reference circuits were integrated directly on-chip. As a result, the sensor can ideally operate from a single external supply voltage, significantly reducing overall hardware complexity.

Another focus of the project was the development of a cost-efficient yet fast LED driver for pulsed UV excitation. An alternative driver topology was investigated that actively removes residual charge carriers from the LEDs, enabling faster turn-off behaviour. Compared to the previous solution, the driver costs were significantly reduced without compromising suitability for time-resolved fluorescence measurements.

Improved suppression of excitation light

A major development focus was the further improvement of optical excitation-light suppression. To achieve this, the floating diffusion node was almost completely shielded from lateral light incidence. In addition to metal shielding, dedicated contact-wall structures implemented using CTW technology were employed. This prevents parasitic excitation light from coupling into sensitive signal regions of the pixel and generating unwanted charge.

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To experimentally evaluate the CTW approach, two different pixel variants were integrated on the same chip: one using the new CTW-based shielding and a reference version based on the pixel architecture of the predecessor projects. Initial characterisation measurements demonstrated an approximately threefold improvement in excitation-light suppression efficiency compared to the previous design.

Compact fluorescence reader for point-of-care applications

In parallel with sensor development, IMMS built a complete reader demonstrator for fluorescence-based LFA tests. The device supports acquisition of both RGB and fluorescence images, features WLAN and Bluetooth connectivity, includes an integrated display, and can operate for a full working day on a single battery charge. Charging is performed via USB-C. Test cartridge identification is implemented through barcode and QR code recognition.

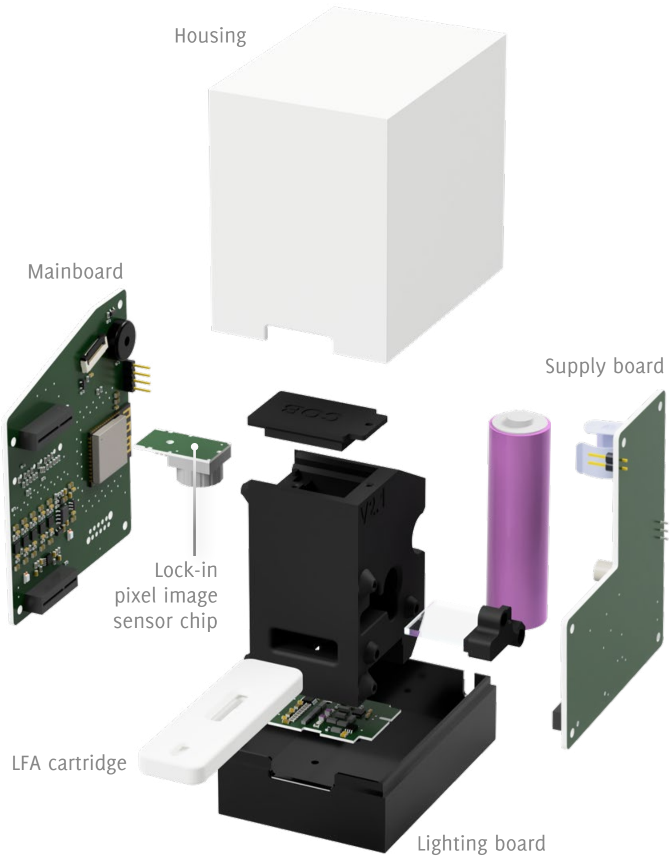

Figure 5:

Exploded view showing the components of the reader assembled as a demonstrator for fluorescence-based LFA tests. Illumination is performed in a transmission configuration from below.

Graphic: IMMS.

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The sensor's two-dimensional image array enables simultaneous acquisition and quantitative evaluation of multiple lines or spots within a single test. Consequently, the reader is particularly well suited for modern multiplex assays involving multiple biomarkers.

A key feature of the system is its large dynamic range, allowing both very weak and very strong fluorescence signals to be measured reliably within the same acquisition. This opens up applications requiring quantitative detection of biomarkers at extremely low concentrations.

One example is cardiac troponin, a highly specific biomarker for myocardial injury and heart attacks. Even small concentration changes can be diagnostically relevant and must be detected reliably. Fluorescence-based lateral-flow tests using europium markers have the potential to provide significantly more sensitive rapid tests than conventional gold-based assays while simultaneously enabling quantitative analysis.

The optical subsystem of the reader was also redesigned compared to previous generations. The objectives were more homogeneous illumination of the test strips, increased robustness against mechanical tolerances, and a reduction of the required sensor area. These improvements resulted in a more compact and manufacturing-friendly overall device architecture.

The device software was further enhanced as well. During measurement, the system can automatically determine suitable acquisition parameters and robustly capture fluorescence signals over a wide dynamic range. In addition, the electronics and PCB design were optimised with respect to future manufacturability and production cost.

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High sensitivity with reduced system complexity

TIRELESS successfully demonstrated a powerful platform for quantitative fluorescence-based lateral-flow testing. The results highlight the potential of specialised CMOS image sensors for compact, cost-efficient point-of-care diagnostic systems of the next generation.

The fully functional demonstrator shows that highly sensitive fluorescence diagnostics no longer require complex laboratory instrumentation and can instead be implemented in portable and user-friendly point-of-care devices.

The combination of dedicated CMOS sensor technology, time-resolved fluorescence measurement, and optimised system integration enables quantitative rapid tests with sensitivities that have traditionally been achievable only with laboratory equipment. TIRELESS therefore opens new opportunities for mobile diagnostic systems and patient-near healthcare applications.

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Freistaat Thüringen

The in-house research group „Time-resolved fluorescence reader for lateral-flow tests“ (**TIRELESS)** was funded by the German Land of Thüringen.

Generator-based design for ultra-low-power mixed-signal circuits

Work on the implementation of the structured, automated Expert Design Plan (EDP) methodology for automated circuit design, simulation and optimisation, as well as for the application of Intelligent IP (IIP). Photograph: IMMS.

Motivation and overview

Ultra-low-power circuits enable energy-autonomous microsystems

Ultra-low-power (ULP) circuits are a key prerequisite for energy-efficient and energy-autonomous microsystems such as battery-free RFID sensors. These systems are particularly attractive for IoT applications, especially where maintenance-free sensors are required for ecological or cost-related reasons, for example in industrial environments. Designing such ULP circuits is inherently challenging because functionality, accuracy, robustness, and energy consumption are tightly coupled at circuit level. System design becomes even more complex when these circuits are used in systems powered by energy harvesting. In such cases, energy is not continuously available from a stable regulated supply independent of the operating state. Instead, the supply voltage itself may become a dynamic signal that depends on harvested energy, the circuit's load behaviour, and the operating sequence of the overall system.

Dynamic supply voltage with multiple dependencies requires design iterations

This coupling is particularly evident in passive RFID systems: the transponder harvests its energy from the electromagnetic field of the reader. As a result, distance, coupling, communication state, and instantaneous energy demand all directly affect the available supply. At the same time, the power consumption of the integrated circuits determines whether the system operates stably and what communication range can be achieved. This creates strong interdependencies between system-level, circuit design, and power supply. As a consequence, conventional strictly hierarchical design approaches reach their limits. Instead, the development process requires numerous iterations along the V-model: an initial system concept is followed by circuit design, then mixed-signal simulations, whose results may in turn necessitate modifications to the system concept. In energy-autonomous ULP systems, these loops are particularly pronounced because energy consumption, supply behaviour, and system functionality are directly interlinked. For passive RFID sensor transponders, for example, the achievable range depends directly on the power demand of the integrated circuits. Early modelling and simulation of energy behaviour are therefore crucial to ensuring the required system properties already before fabrication.

Conventional design restricts the number of necessary iterations

Conventional design flows provide only limited support for such iterative processes because many steps still have to be carried out manually and are therefore time-consuming. This limits the number of possible iterations and makes systematic parameter studies or optimisations more difficult. Generator-based design approaches address this challenge by formalising and automating the design process itself. They translate expert knowledge into executable design flows, enabling fast and reproducible generation and adaptation of circuits. The goal is to significantly accelerate iteration cycles within the V-model and thereby enable broader design-space exploration and more robust system designs.

Generator methods for more efficient iterations in circuit design

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In the BMFTR collaborative project HoLoDEC, such approaches were developed and practically evaluated together with partners from industry and research. IMMS investigated them using an ultra-low-power RFID sensor transponder with an integrated

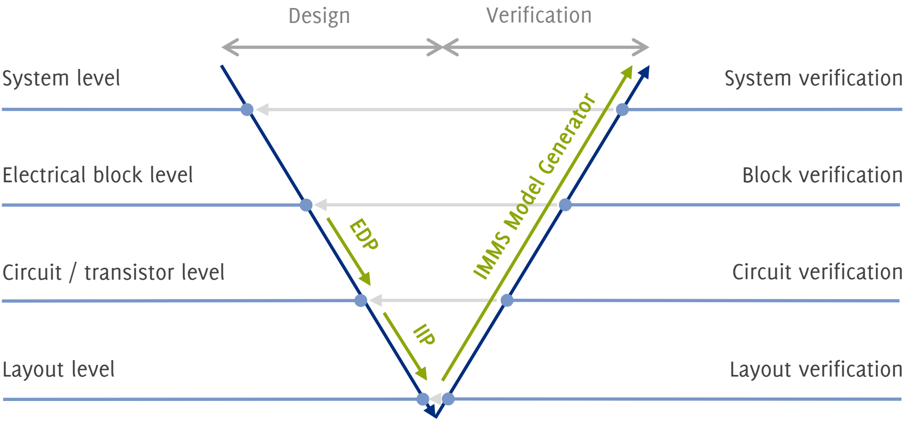

Figure 1: Integration of generator-based implementation approaches and automated energy behaviour models into a V-model-oriented design flow. Graphic: IMMS.

analog front-end (AFE) as an example. The institute employed two key generator approaches from the project consortium: the Expert Design Plan (EDP) methodology, contributed by Reutlingen University and jointly extended and adapted with IMMS for new ULP circuits; and the Intelligent IP (IIP) methodology, developed by Fraunhofer IIS/EAS in Dresden and likewise advanced together with the partners to meet the requirements of the specific mixed-signal design. IMMS thus acted both as a user of these generator approaches and as an active development partner. In addition, the institute developed its own methods for energy behaviour modelling to efficiently support the transition from system-level to implementation as well as the feedback loop through verification methods. Within the project, procedural top-down approaches for implementation were combined with bottom-up-oriented verification methods along a V-model-based design flow as depicted in Figure 1.

Solution in detail – IMMS contribution

Development of the design strategy based on a passive ULP front-end

The core of IMMS's work was the development of an ultra-low-power analog front-end for reading resistive sensors used to measure electrical resistance changes caused, for example, by variations in temperature, pressure, or humidity in a passive RFID transponder. The aim was fully battery-free operation, with the transponder harvesting all of its energy exclusively from the electromagnetic field of a reader. The AFE therefore had to capture sensor signals reliably while operating with extremely low power consumption. IMMS first developed a conventional circuit topology for the AFE to satisfy the functional requirements and strict energy constraints. Based on this, the team gradually transferred the design into generator-based methods. The goal was to systematically capture and preserve the underlying design strategy and make it reusable for future applications. The circuit design thus served not only as a demonstrator for a specific application, but also as a practical test case for the methods developed in the project.

Adapting the EDP methodology to new ULP circuits

A major focus was the application of the EDP methodology developed by Reutlingen University. Together with the project partner, IMMS adapted this methodology to the requirements of new ULP circuits and applied it to key blocks of the RFID sensor front-end. Therefore, IMMS abstracted the design flow of an operational-amplifier-based switched-capacitor amplifier in the form of an executable generator. This included automatic schematic generation, initial sizing based on given specifications, followed by simulation and iterative optimisation. The EDP approach thus transformed expert knowledge into parameterisable scripts that communicated with the Cadence design environment and supported key steps of the analog design process.

In doing so, IMMS deliberately integrated gm/Id-based design methods to efficiently determine and systematically adjust transistor operating points. These methods exploit the direct relationship between a transistor’s desired gain or bandwidth behaviour and the required current consumption to achieve current efficiency, simplicity, scalability, and consistency/transferability. The initial sizing took into account specifications such as gain, sampling rate, input and output voltage swing, accuracy, and linearity. Additional constraints such as minimum and maximum transistor dimensions and area limitations were also considered. The resulting sizing parameters were then back-annotated into the schematic and verified by simulation.

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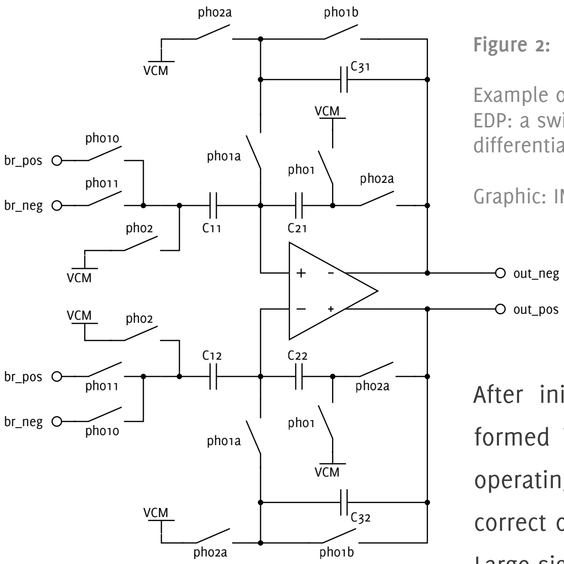

Figure 2:

Example of a circuit topology addressed by EDP: a switched-capacitor amplifier with a fully differential operational amplifier.

Graphic: IMMS.

After initial sizing, the generator performed iterative optimisation. First, DC operating points were analysed and incorrect operating points were identified. Large-signal operating points were corrected by adjusting transconductance efficiency (gm/Id) or the gate-source voltage; small-signal parameters were adjusted, among other means, by varying transistor lengths and gm/Id values. This was followed by stability and AC analyses to assess figures such as phase margin, loop gain, and bandwidth. In addition, transient behaviour was examined, including step response and slew rate. The results showed that the generator-based circuits reliably met the required specifications. For the operational amplifier, the amplitude response, phase response, and step response of the EDP-generated design were comparable to the manually developed reference design. In some parameters, such as bandwidth, the generator even achieved slightly better values. For the entire switched-capacitor amplifier, the EDP execution time was around ten minutes. The project thus demonstrated that future circuits with the same or similar topology can be generated much faster and adapted more efficiently to changed requirements.

Adapting the Intelligent IP methodology for automated layout generation

In addition, IMMS worked with the Intelligent IP (IIP) methodology developed by Fraunhofer IIS/EAS in Dresden. The IIP methodology provides generators for frequently used transistor structures such as current mirrors or differential pairs,

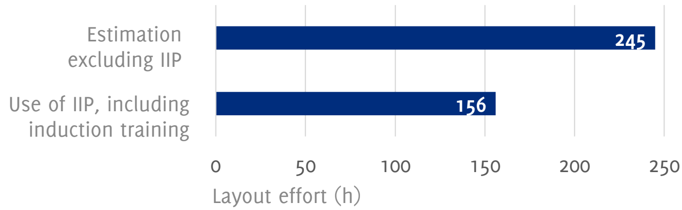

Figure 3: Statistics on the required layout effort with and without the use of IIP indicate a time saving of approximately 36%. Graphic: IMMS.

enabling flexible and consistent generation of the symbol, schematic, and layout of these blocks based on parameterised inputs. Together with the project partner, this methodology was adapted and used for automated layout generation in the specific application case. As part of this work, IMMS and Fraunhofer IIS/EAS jointly developed an IIP for a capacitor array, supporting the automated physical implementation of a key analog circuit component. In this way, the IIP tools supported the physical realisation of the previously developed circuits and complemented the EDP-based approaches at layout level. Together, they resulted in a more continuous design flow that addressed not only sizing and schematic generation, but also steps of the physical implementation.

Method for automated energy behaviour modelling of mixed-signal circuits

Another major contribution of IMMS was the development of a method for automated energy behaviour modelling of mixed-signal circuits. The goal was to evaluate energy consumption already at an early system-design stage without having to perform time-consuming transistor-level simulations. This approach complemented the top-down-oriented generators as a bottom-up-oriented verification method. ULP circuits pose particular challenges for modelling. They typically exhibit very different current ranges: extremely small currents in standby mode, whereas substantially higher currents may flow during a measurement. For the energy balance, moreover, not only the instantaneous current value is relevant, but also its integral over time. Errors in long-duration operating states can therefore have significant effects on the overall validity of the model. In addition, digital control signals such as enable or start-of-conversion signals strongly affect current consumption, making the relationship between inputs, states, and current draw highly nonlinear.

To address this, IMMS developed a methodological workflow comprising automatic generation of suitable testbenches, validation of the resulting data sets, and subsequent model generation. For data generation, the team used reduced and robust sampling methods such as Latin Hypercube Sampling to cover the input space efficiently and as uniformly as possible. This made it possible to improve the training data set in a targeted manner without letting the simulation effort grow uncontrollably. For the actual model generation, IMMS evaluated various regression approaches and ultimately employed linear decision trees. These combine the ability of classical decision trees to represent discrete control states with linear or polynomial regression functions in the individual leaves. This made them especially suitable for mixed-signal circuits in which continuous quantities such as supply voltage, temperature, or reference voltage jointly determine energy consumption together with discrete logic signals. The resulting energy models enabled realistic system-level estimation of current consumption and thereby supported early verification of the overall system. This was particularly relevant for the RFID demonstrator, because its range depends directly on the available and consumed energy. As a result, design decisions concerning topology, system architecture, and operating strategy could be evaluated earlier and more systematically.

Demonstrator implementation

The developed methods were ultimately brought together in a demonstrator. IMMS implemented two integrated circuits in X-FAB CMOS technology XT018 with a 180 nm feature size. The test chip D1038A contained the analog front-end and an I²C interface and served for detailed laboratory characterisation of the front-end. The second chip, D1036A, integrated the analog front-end into a complete RFID transponder and was intended for demonstrator investigations under realistic operating conditions. Initial characterisation measurements have since confirmed that the fabricated chips largely achieve the targeted properties. The results on applying the EDP methodology to the ultra-low-power sensor front-end were presented and published in 2025 at the international SMACD conference.

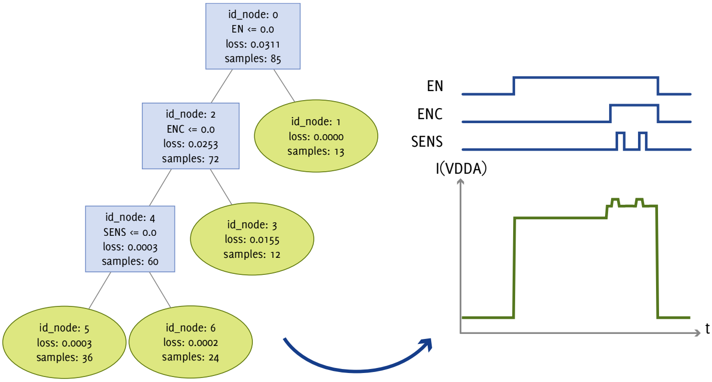

Figure 4: Example of a linear decision tree for energy behaviour modelling. Regression models for current consumption are located in the leaves.

Graphic: IMMS.

Summary and Outlook

The work carried out in the project demonstrated that generator-based design approaches have considerable potential for the development of ultra-low-power mixed-signal circuits. In particular, the EDP methodology, adapted jointly with Reutlingen University, made it possible to structure, automate, and preserve complex design processes for long-term reuse. At the same time, the practical application showed that the creation of such generators still requires substantial initial effort. Further improvements in the methodology, tool support, and usability are therefore necessary to establish the approach more broadly in industrial and scientific development processes.

The IIP methodology used and adapted together with Fraunhofer IIS/EAS in Dresden made an important contribution to the automation of physical design within the project. It offers significant potential to further accelerate layout steps and to link them more closely with schematic- and specification-driven design flows. In the future, this can help make the transition from architectural decisions to physical implementation even more consistent and faster.

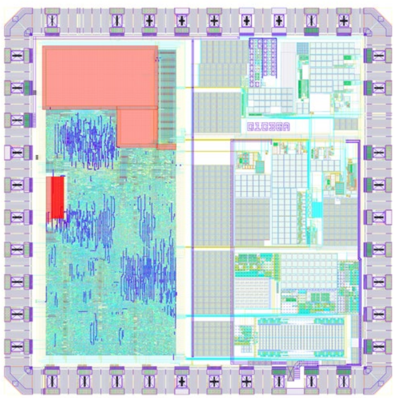

Figure 5: Layout of the complete RFID transponder IC with integrated analog front-end for demonstrator investigations. Graphic: IMMS.

The developed energy behaviour models also open up new possibilities for the early verification and optimisation of energy-efficient systems. They make it possible to test system concepts more quickly against realistic energy assumptions and thus to move through iterations within the V-model more efficiently. A future focus will be on further generalising the models, improving their integration into generator-based workflows, and validating their applicability on additional circuits.

With the fabrication of the demonstrator chips, a decisive project milestone has been completed. The subsequent characterisation of the circuits and their integration into system-level tests form the basis for further evaluation and improvement of the developed approaches. In the long term, the results will help establish generator-based methods in analog and mixed-signal circuit design and significantly accelerate the development of energy-autonomous microsystems.

Contact person: Martin Grabmann, M.Sc., martin.grabmann@imms.de

Reference:

Application of the Expert Design Plan Methodology on an Ultra-Low-Power Sensor Frontend. Lorenz Renner. Ralf Sommer. Yannick Uhlmann. *2025 21th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD), July 7-10, 2025, Istanbul, Turkiye, pp. 1-4,* **DOI: doi.org/10.1109/SMACD65553.2025.11092185**

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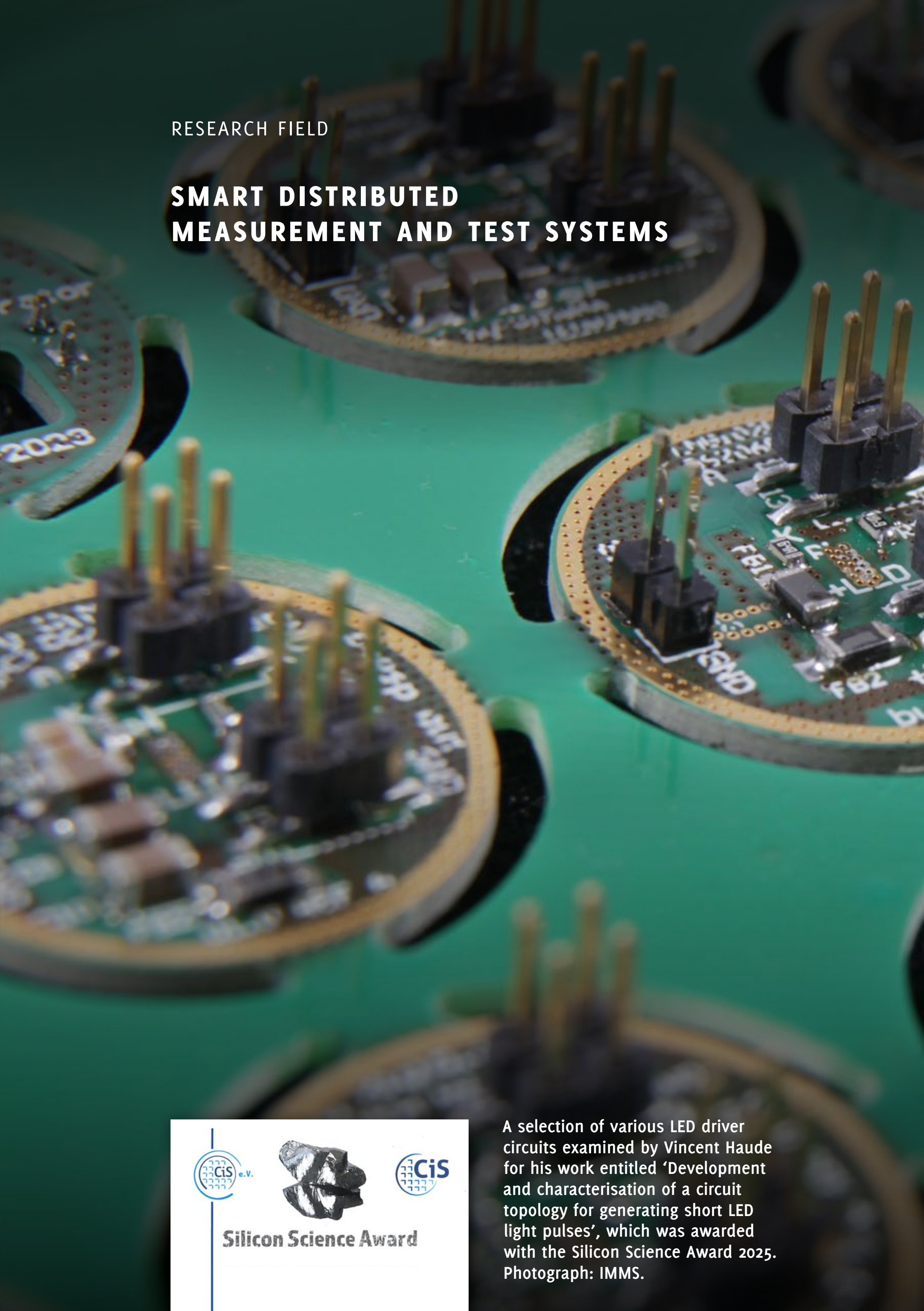
RESEARCH FIELD

SMART DISTRIBUTED MEASUREMENT AND TEST SYSTEMS



A selection of various LED driver circuits examined by Vincent Haude for his work entitled ‘Development and characterisation of a circuit topology for generating short LED light pulses’, which was awarded with the Silicon Science Award 2025. Photograph: IMMS.

› *Integrated sensor systems*
› *Distributed measurement + test systems*
› *nm-precise 6D direct drives*
› *Contents*
* *Funding*

Integrated sensor ICs represent the heart of sensor and measurement systems. These can be wireless sensors, handheld diagnostic devices or high-performance stationary device solutions for machine monitoring, for example.

For increasingly performant sensors, we are working on the following research questions

Increasingly performant sensors and their rapidly expanding number lead to immense amounts of data, which are ever more pushing previous technologies to their limits when it comes to transmitting, processing and using them. Therefore, it will be necessary to design systems for sensing, measuring and testing in such a way that they can validate, process and evaluate data automatically in the future. We intend to achieve this by directly incorporating intelligence into the devices. Interconnecting these systems creates the possibility of distributing the tasks in the network. However, new challenges arise in the form of dynamic aspects due to network protocols and changing tasks over time.

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In this research field, we therefore focus on three questions: How can sensor data be automatically processed into usable information as close as possible to the point of origin in a fast, cost-effective and energy-efficient way? What additional information can be obtained with the help of distributed sensor systems? How can such a system be modelled based on different subsystems to evaluate energy requirements, the optimal distribution of functionalities in the network and the influence of topology decisions?

With our solutions we address the following applications

To address our research questions, we work on the one hand on the analysis of distributed IoT systems to implement energy- and resource-optimised embedded systems, for example for the “Internet of things” (IoT) or autonomous sensor networks for environmental monitoring or smart city applications. On the other hand, we conduct research on embedded artificial intelligence (AI) to be able to efficiently implement AI algorithms on highly resource-constrained systems, e.g. for automation technology and Industry 4.0.

In the field of real-time data processing and communications, we optimise embedded systems for signal processing and data transmission in real time so that, for example, connected, spatially distributed edge AI systems can communicate smoothly. In addition, we develop concepts and implementation architectures for modular and mobile test systems. With these modular hardware-software platforms, integrated circuits and embedded systems for various applications can be tested and characterised extensively, yet quickly and flexibly.

Highlights of 2025 in our research on smart distributed measurement and test systems

Silicon Science Award for fast LEDs for in-vitro diagnostics

Vincent Haude, electrical engineer and researcher at IMMS, was honoured with the Silicon Science Award at the international Waferbond25 conference in Chemnitz on 3 December 2025. His award-winning thesis, "Development and characterisation of a circuit topology for generating short LED light pulses," was supervised at IMMS and Technische Universität Ilmenau. The result is a very compact system that brings significant improvements in terms of the dynamics and optical switching times of LEDs for the development of systems for time-resolved fluorescence measurement. The work of the Thuringian scientist is a significant contribution to integrated sensor systems for in-vitro diagnostics. To this end, IMMS researches and develops solutions for point-of-care devices for rapid, patient-oriented diagnostics.

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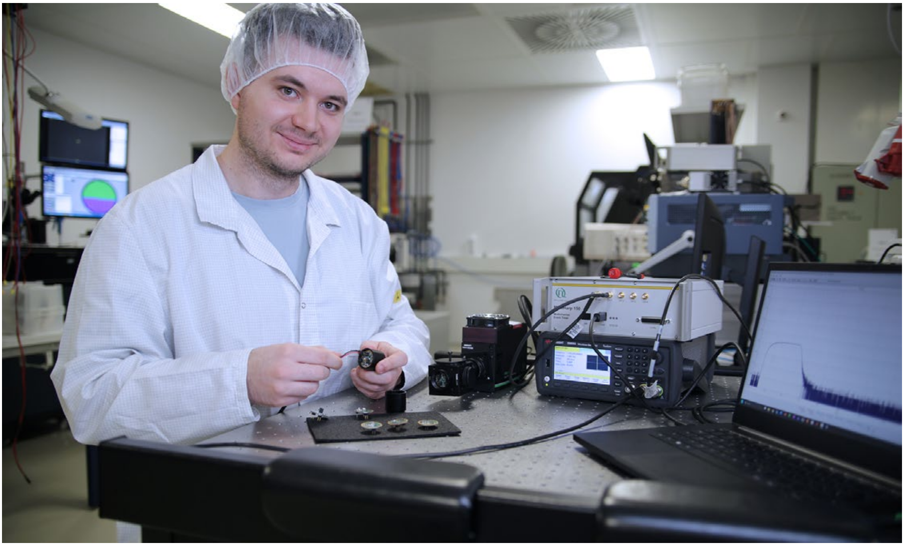
Race for decay times in fluorescence markers decisive

"Vincent Haude has produced an outstanding piece of work on a very challenging topic that strengthens Thüringen's innovative power in the key sensor technology sector," said Prof. Hannes Töpfer, Head of Theoretical Electrical Engineering at Technische Universität Ilmenau. The bachelor's thesis addresses a topic that is currently very relevant in the broader research context: "With increasingly sensitive sensor systems, analytical methods in medicine and environmental analysis can be improved and are therefore of considerable social interest," Töpfer continues. In diagnostics, sensors are used to measure the fluorescent properties of biological samples.



Vincent Haude, electrical engineer and researcher at IMMS, is preparing one of the LED driver circuits for a measurement. For his work, he was honoured with the Silicon Science Award on 3 December 2025 at the international Waferbond25 conference in Chemnitz. Photograph: IMMS.

“Fluorescent dyes are used as markers in in-vitro diagnostics, for example,” explains Vincent Haude. With their help, even the smallest concentrations of pathogens can be detected using analytical equipment in special laboratories, which would not be possible with standard tests, Haude continues. “This is naturally of interest if, like IMMS, you want to build mobile diagnostic systems.” The dyes emit light of a characteristic wavelength when excited by light of a different wavelength. Depending on the dye, this fluorescence is visible for a few nanoseconds to microseconds and can therefore be measured, provided it does not overlap with the excitation light. IMMS develops semiconductor-based microelectronic chips that are used to measure the intensity of the fluorescent light over time. The emitted light is measured after the excitation light from an LED has been switched off and has decayed. “The dyes can also be excited in the same way with lasers, but these are relatively expensive at these wavelengths,” Haude continues. Optical filters can also be used to separate excitation light and fluorescence light, as in large laboratory analysers, but this increases the installation space and costs.

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“We want to develop cost-effective mobile systems, which is why we want to use standard LEDs as pulse light sources at IMMS,” explains Haude. The faster and better they can be switched on and off, the more flexible and reliable they are for use with different fluorescent dyes and thus applications.

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To achieve this goal, Vincent Haude used his detailed research into the physical fundamentals to identify the relevant parameters that influence the dynamic switching behaviour of LEDs. Using these findings, he selected commercially available standard LEDs with regard to their switching behaviour, researched and developed pulse driver circuits for LEDs, simulated selected circuits, created high-frequency-optimised layouts and built them on printed circuit boards as a characterisation setup. He measured these circuits and the selected LEDs both electrically and optically.

“Vincent Haude was able to reduce the afterglow of LEDs to a few nanoseconds with the help of optimised circuits,” explains Alexander Rolapp, specialist for the characterisation and testing of integrated circuits at IMMS and supervisor of the bachelor's thesis. “The limit was always the LED itself and never the circuit.” On this basis, Vincent Haude developed a very compact LED pulse system that not only significantly improves the optical dynamics and optical switching times of LEDs, but can also be easily integrated into existing setups. “Actively switching off LEDs in this way shifts their dynamics for the applications we are interested in to areas that are otherwise reserved for lasers,” Rolapp summarises.

www.imms.de/modtest

Thus, Vincent Haude’s findings and his characterisation setup are an important building block that will significantly advance future research and development in time-resolved fluorescence.

A driver circuit for investigating commercially available LEDs for time-resolved fluorescence measurements in the nanosecond range, which opens up new applications in in-vitro diagnostics.

Photograph: IMMS.

“For my thesis, I benefited not only from the state-of-the-art measurement equipment at IMMS. To understand LEDs as well as possible, I studied solid-state physics, optoelectronics and electrical engineering. Here, I was helped by the in-depth knowledge of my colleagues at IMMS, who were able to classify and answer even the most complicated questions,” says Haude, expressing his gratitude for their support. Born in Thüringen, Haude took advantage of opportunities such as the Basic Engineering School at Technische Universität Ilmenau early on to combine theory with practice, and later became a supervisor there himself. He has been at IMMS since 2021 – first as an intern and assistant, and since completing his bachelor’s degree as a research assistant. “The Silicon Science Award shows that the mix of theory and practice that we offer at Ilmenau TU together with IMMS is bearing fruit,” says Töpfer. Haude is perfectly prepared for a career start in application-oriented research, as practised at IMMS and incorporated into products from partners in medical technology, sensor technology and industry, Töpfer continues. At the same time, thanks to his solid education, Haude has all the tools he needs to jump straight into research and development in industry or to found a start-up. “I’m excited to see where the journey takes me,” comments Haude with a wink.

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Kick-off meeting on 11 September 2025 in Erfurt for the project "Inline cleaning process for washing media in resin-based 3D printing processes" (Inline3D), which was launched in June 2025. Photograph: IMMS.

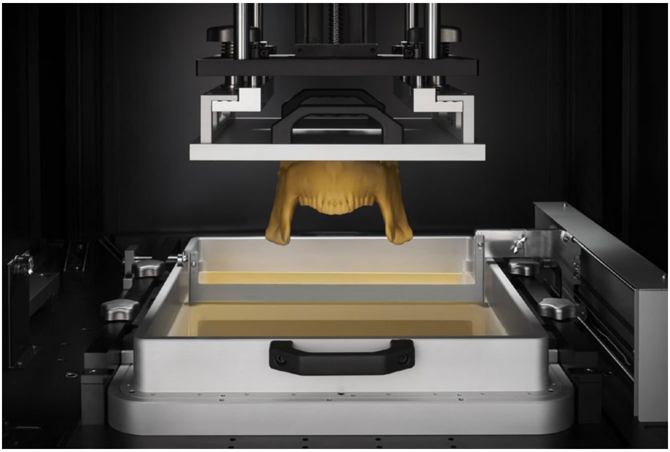
Inline3D* project launched: Inline cleaning system for washing media in resin-based 3D printing production

www.imms.de/inline3d

On 11 September 2025, IMMS, IL Metronic and BURMS presented details of the Inline3D project, which is funded by the German Land of Thüringen and the EU and was launched in June, to the Thüringer Aufbaubank (bank to support development in Thüringen) in Erfurt. In this project, which will run for almost two and a half years, sensor technology, cleaning and fluidic modules are being developed to clean washing media in resin-based 3D printing production inline – directly in the manufacturing process – for the first time. The aim is to minimise the use of environmentally and health-damaging as well as cost-intensive substances in the washing media required for 3D printing.

Resin-based 3D printing processes generate harmful waste

In resin-based 3D printing production, the 3D printed objects are cleaned with special washing media. These contain substances that are harmful to the environment and health and are currently often disposed after one use instead of being recycled. The reason for this is that, at present, recycled washing substances are usually not sufficient to clean the printed objects of unhardened resin.



The Inline3D project is researching inline cleaning for washing media in resin-based 3D printing production. The image shows customised solutions from a 3D printer for precision manufacturing for industry and research.

Photograph: BURMS.

Cost factor washing media difficult to minimise so far

The consumption of cleaning media is also a significant cost factor in the production process. So far, cleaning media is only processed on a large industrial scale. Available cleaning devices are large, unhandy, energy-intensive and can only be used ‘offline’. This means that the media to be cleaned must be transported to the cleaning system in separate process steps and later returned to the 3D printing process in some cases. Automatic cleaning during the ongoing production process with permanent monitoring of the properties of the media is not yet available.

Inline treatment allows further use of the cleaning medium

The Inline3D project is developing a treatment process for washing media that removes contaminants directly during the production process and then returns the treated washing medium to the cleaning process. This treatment converts environmentally hazardous and harmful components into harmless waste products that do not need to be disposed of as hazardous waste.

www.imms.de/inline3d

Sensor-based monitoring of the contamination level can extend the service life of the washing medium and optimise the quality of the cleaning process. The aim is to use resources more efficiently and minimise pollutants and costs in 3D printing production processes.

Thuringian partners pool expertise in sensor technology, UV irradiation technology and 3D printing

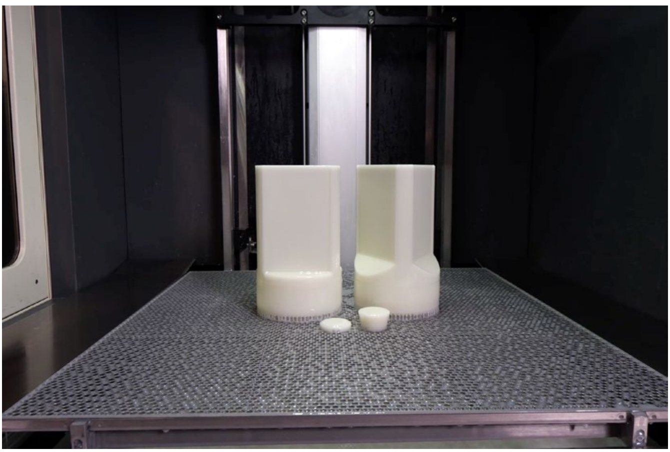
The regional alliance of the three Thuringian project partners BURMS 3D Druck, IL Metronic Sensortechnik and IMMS promotes innovation and the further development of existing expertise in the field of 3D printing in the German Land of Thüringen.

IMMS is coordinating the project and developing a sensor-based measurement method to quantify the degree of contamination in the washing medium. IL Metronic is using its expertise in UV irradiation technology to transfer the measurement method to a sensor module and develop an irradiation module for separating out dissolved resin residues. BURMS is contributing its expertise in commercial 3D printing solutions, implementing the fluidics and process integration in the project, and ensuring device safety, disposal and biocompatibility.

Faster production and more resource-efficient small batches possible

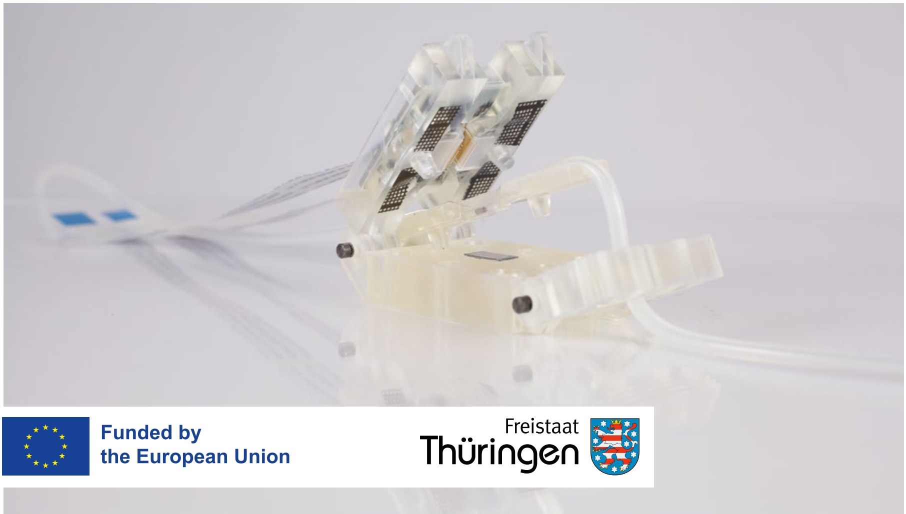
Due to the advantages of fast production times and application- and customer-specific customisation of individual items, growth is expected particularly in medical applications. In addition to the technological advancement of the 3D printing technologies of the partner BURMS, the aim of the project is also to use the technological findings to further develop those 3D printing systems that currently do not process the washing medium at all.

www.imms.de/inline3d



The Inline3D project is researching inline cleaning for washing media in resin-based 3D printing production. The image shows customised solutions from a 3D printer for precision manufacturing for industry and research.

Photograph: BURMS.



Contacting unit for preliminary investigations with graphene chips from FSU Jena for the development of evaluation electronics for graphene sensors to be used for on-site detection of micropollutants in wastewater. Photograph: IMMS.

Project launch of MikroGraph*: Evaluation electronics for new, highly sensitive graphene sensor technology for on-site detection of micropollutants in wastewater

Micropollutants in wastewater determined too slowly to date

80 percent of micropollutant pollution in wastewater from large municipalities must be avoided from 2035 onwards. This requirement of the EU Municipal Wastewater Directive can only be met by collecting comprehensive data and treating pollution in a targeted manner.

www.imms.de/mikrograph

This will be difficult to achieve with the current standard analysis of individual samples, which are sent to central laboratories and tested for pharmaceutical residues, pesticides or plasticisers, for example. This approach is time-consuming and does not allow for immediate response to acute pollution.

In future, micropollutants in wastewater are to be analysed on site

In the MikroGraph project, an innovative analysis system for the on-site detection of micropollutants in wastewater is being developed. The aim is to quantify at least three of twelve relevant substances from the EU Directive (91/271/EEC) with high precision and a low detection limit (0.003 µg/l).

› Integrated sensor systems
› Distributed measurement + test systems
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* Funding

Central sewage treatment plant in Jena-Zwätzen. The aim of the 'MikroGraph' research project is to directly measure the concentration of pollutants in wastewater. Photograph: Jens Meyer (Jena University).

This will be achieved by combining graphene sensor technology, separation column technology and mass spectrometry, which are being developed in parallel and mutually validated within the project. These three technologies will be combined with microfluidics and intelligent control to create a compact, automated solution for sewage treatment plants and industry.

By comparing measurement results from the same sample, deviations can be detected, causes analysed and the strengths of each method specifically utilised. The result is a robust on-site analysis system that detects micropollutants precisely, efficiently and reliably.

IMMS develops evaluation electronics for graphene sensors

IMMS will develop special evaluation electronics for graphene sensors. To this end, IMMS designs, simulates and characterises circuits for precise current measurement in the nA range and fast signal acquisition. It implements multi-channel electronics, integrates them into the laboratory simulator and controls its processes in real time. Finally, the results will be incorporated into a compact system for drinking water and wastewater analysis to enable reliable on-site micro-pollutant detection.

www.imms.de/mikrograph

GraFET chip with attached flow cell for preliminary tests in the Multi-Interact project. Photograph: IMMS.

Projec start of Multi-Interact*: For health research, a highly parallelised multiplex system is being developed to precisely and kinetically determine binding energies between biomolecules

www.imms.de/multi-interact

In health research, it is necessary to determine various biomarkers of the biomolecules to be analysed using multiplexing technologies for effective development processes in the fields of diagnostics and pharmaceutics. To this end, interaction processes between the molecule groups are to be analysed using parallel measurements.

With the help of functionalised carbon nanomembranes on graphene field effect transistors (GraFET) and an electronic circuit for measurement and evaluation, it is possible to determine these biological interactions. If these GraFETs are multiplied with different functionalisation layers, the kinetic binding energies of different biomarkers can be determined in parallel by multiplexing. The measurement is thus scalable and can later enable a low-cost device design.

Research tasks of the project partners

IPHT Jena will develop miniaturised sensor arrays for the multiplex system and FSU Jena will develop highly sensitive graphene with carbon nanomembranes. IMMS will develop the electronic, highly parallelised readout methods and electronics and the FZMB will research the possibilities for detecting the label-free binding of active ingredients and substances in complex biological matrices.

IMMS measurement electronics

The binding of biomarkers on the surface of the GraFET causes charge carriers to accumulate there. This variation correlates with the change in the charge neutrality point (CNP) of the GraFET. To this end, IMMS will develop, construct and characterise measurement electronics that determine the CNP of several GraFETs in parallel.

An automated test setup will then be used to visualise the readout of an up to 100-fold GraFET array in real time on a PC.

www.imms.de/multi-interact

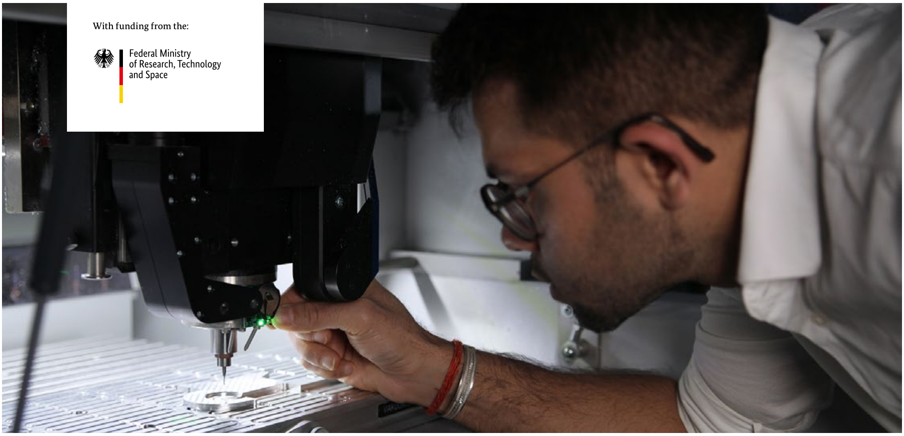
Rick Pandey (IMMS, centre) on 11 December 2025 at the Thuringian awards ceremony organised by PATON | Patent Centre Thüringen at Technische Universität Ilmenau as part of the iENA Inventors' Fair. Photograph: IMMS.

Extended service life for self-teaching wireless sensors for industrial maintenance: IMMS patent for edge AI solution wins bronze medal at iENA 2025

The IMMS patent 'Method and sensor arrangement for monitoring the function of a machine component' was awarded a bronze medal on 11 December 2025 at the Thuringian award ceremony of PATON | Landespatentzentrum Thüringen (Patent Centre of the German Land of Thüringen) at Technische Universität Ilmenau in the competition at the iENA inventors' fair. At the beginning of November, PATON submitted the work to the competition at iENA in Nürnberg, Germany, on behalf of the inventor Rick Pandey. Core to the patent is a new method for data-reduced communications between wireless sensor nodes and monitoring systems, which significantly reduces the energy consumption of wireless sensors. This allows users or manufacturers of wireless sensors to use them for industrial maintenance with condition monitoring and predictive maintenance, even in large quantities and in hard-to-reach places, for years to come.

Energy consumption of wireless sensors and large amounts of data critical

Machines and industrial plants are often monitored and analysed in real time using wireless sensors to detect potential problems or deviations from normal operating conditions at an early stage and predict maintenance requirements. However, this can lead to limitations: if the sensors are located in many or hard-to-reach places



Rick Pandey with an AI-based embedded system for machine diagnosis. Edge AI systems like these are being researched in terms of their energy efficiency and overall system energy modelling in the HoLoDEC project. Photograph: IMMS.

and are required to operate reliably for years, their energy consumption is critical in terms of battery life. The sensor technology used for monitoring also generates a large amount of data. So far, this data can only be transmitted to the central monitoring device at high energy costs. In addition, defects in machines occur very rarely or not at all during normal operation, and certain fault conditions, such as defective bearings and machine parts, cannot be easily reproduced.

www.imms.de/holodec

New algorithm learns good conditions – wireless sensor only transmits deviations

With the patented Edge AI solution, data is processed directly on the sensor node and reduced for radio transmission, which lowers its energy requirements and thus increases its service life. Interference data and error states no longer need to be recorded in advance.

The much-cited term ‘edge AI’ combines edge computing and artificial intelligence. This allows algorithms and machine learning to be executed directly on interconnected wireless sensors – locally or with an internet connection. While edge computing enables data to be stored close to machines and systems, AI algorithms process the data directly at the edge of a network or at the interface to the higher-level network and can provide real-time feedback on the machine status.

The new algorithm developed at IMMS collects data and learns normal machine behaviour patterns directly on the sensor, largely without supervision. The regular behaviour patterns of a plant and certain novelty criteria that indicate deviating behaviour are learned from the data recorded on the wireless sensor. Data is only sent to a central monitoring system if the calculated novelty value deviates from the normal criteria for 'healthy behaviour'. This completely eliminates the need to transfer raw data to a central monitoring system. This on-device learning and subsequent retraining make the algorithm generalisable for various industrial scenarios and robust against possible data drift. The method for recognising the novelty value of data combines mathematical procedures in a specific sequence for ongoing condition monitoring and predictive maintenance over many years.

On-device data reduction through singular value decomposition and correlation

To this end, the proper operation or good condition of, for example, a bearing or a machine is first recorded, its characteristics are automatically determined by singular value decomposition, and a threshold value is determined on this basis to be able to detect deviations. This threshold value is then further improved by learning certain anomalies and conditions.

To reduce the data set on the sensor node so that as little data as possible needs to be transferred to the monitoring system, only a certain number of the dominant singular values are used with their associated information. In the application, newly recorded vibration values are analysed using canonical correlation analysis. Changes in condition are qualitatively recorded based on the differences between the learned characteristics of the good condition and the newly recorded ones.

The process can be implemented in various applications for machine monitoring and is available for licensing.

German patent: DE 10 2024 100 703 B3, IP available, patent applicant/holder: IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH (IMMS GmbH), inventor: Rick Pandey.

At the 2025 embedded world trade fair, IMMS presented its energy-efficient edge AI sensor system – developed as part of the HoLoDEC project – for industrial monitoring applications at the Thuringian joint booth.

www.imms.de/holodec

IMMS at embedded world: AI without the net: Energy-efficient edge AI sensor system for industrial monitoring applications

IMMS presented solutions for automatable processes, services and systems at embedded world in Nürnberg, Germany, from 11 – 13 March 2025. IMMS showed its 'AWARE' development at the joint Thüringen booth in hall 4, stand 410. The small sensor system with local AI was developed to recognise errors directly in industrial processes and support decisions on predictive maintenance. As a research result, AWARE is the basis for developing monitoring applications in industry together with partners.

AI without the net?

Anyone who has ever wanted to ask the AI assistant on their smartphone in a dead zone knows that the AI models and algorithms do not run locally, but on powerful servers with lots of storage space. Edge AI systems such as the AWARE demonstrator

https://youtu.be/Yv-XzoZxICQ

The “AWARE” demonstrator (Advanced wireless AI-enabled real-time environment) incorporates key findings from the internal AI research group. This energy-efficient edge AI sensor system can be used to develop monitoring applications in industry. Find out more in the technical article on anomaly detection with edge AI and unsupervised learning for smart machine monitoring – and in the video. Photograph: IMMS.

Read the specialist article

system developed by IMMS in the HoLoDEC research project show that the answer can still come directly from a small device ‘in your pocket’.

www.imms.de/holodec

In AWARE (advanced wireless AI-enabled real-time environment), the ‘artificial intelligence’ is integrated directly into the sensor. This allows decisions to be made in real time without having to go via the cloud. Automated adaptation to new environmental conditions opens up a wide range of applications, such as fault and wear detection in production.

Demonstrator with potential for monitoring developments

A demonstrator shows AWARE being used to monitor ventilators – a simple example application with great transfer potential. AWARE records vibration measurement data, analyses it and classifies the current status of ventilators. The system contains a vibration sensor that can record vibrations of up to 6.4 kHz and a microcontroller with an integrated radio transceiver.

The sensor data is processed by clustering using an unsupervised machine learning process. An 'intact' ventilator is taught in the process. The training takes place exclusively on the microcontroller of the sensor node.

Another 'intact' and a 'defective' ventilator can then be recognised and classified accordingly without the data having been recorded beforehand. The result is displayed via a green or red LED. The data can also be transmitted to an edge device via BLE (bluetooth low energy) to save energy.

Lots of research for small sensor nodes

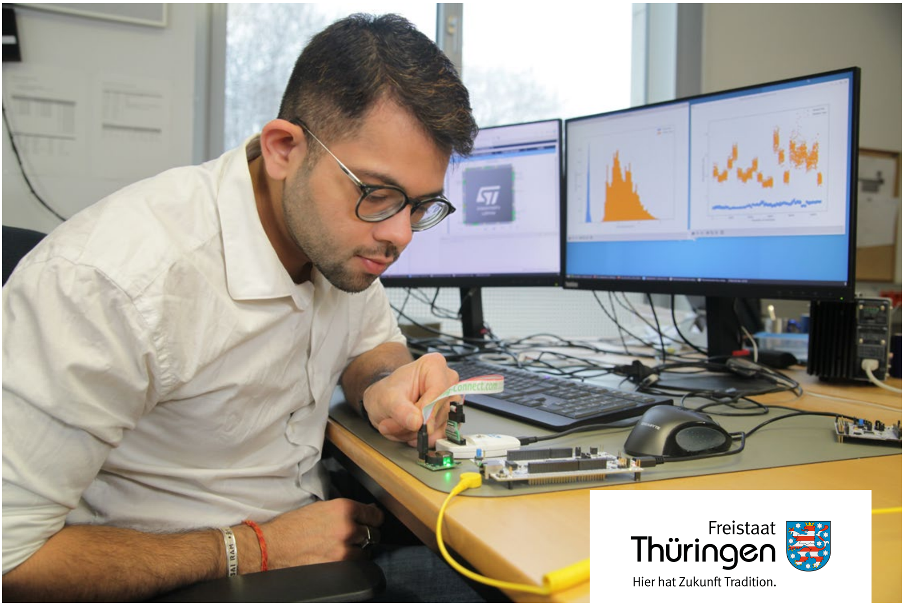
In projects such as HoLoDEC, IMMS is creating the basis for transferring research results to industrial applications with developments such as AWARE.

In HoLoDEC, IMMS is researching how to optimise the use of AI algorithms on resource-limited devices for IoT applications. To this end, IMMS is developing energy-efficient edge AI systems with energy-optimised power distribution between as much sensor-related data processing as possible and as little outsourcing of tasks to the network as possible.

The challenge is that AI models and algorithms no longer only run on powerful servers with a lot of memory, but are to be used on microcontrollers for which they were neither developed nor are transferable 1:1 and must be adapted accordingly. However, current research is often limited to the development of a powerful AI model on a server.

The AWARE development shows that there is an alternative. At embedded world, IMMS was looking for new R&D partnerships in the field of adaptive edge AI systems for automation technology and Industry 4.0 as well as for monitoring and maintenance to initiate application-specific further developments of the AWARE system.

www.imms.de/holodec



In 2025, IMMS supported the start-up OmniSent through the iHUB research start-up grant, funding research into machine-learning algorithms for local signal processing on resource-constrained sensor nodes. OmniSent had intended to use these for solutions to continuously monitor leaks in compressed air pipes. Photograph: IMMS.

iHUB*: Start-up support for innovative ideas

In 2025, IMMS was once again involved as a research partner in the iHUB ideas competition, as part of the InSignA Centre of Excellence. This provides start-up support for innovative ideas on the topics of sensor technology, digitalisation and assistance systems. In a competition, the ideas are presented to a jury from science, business, public institutions and venture capital companies. The best ideas are then selected for funding and supported with research services from the partners involved. There are various objectives for advancing the idea, from demonstrators and prototypes to market analyses and feasibility studies. The projects are carried out by members of the performance centre for up to six person-months, including access to experts, laboratories and material resources.

www.imms.de/ihub

Task and partner

Omnisent GmbH was founded in January 2025. The aim of the iHUB project was to develop an innovative IoT-based sensor system for the automated, real-time detection and localisation of compressed air leaks. In industry, up to 10 per cent of electrical energy is used solely to generate compressed air. Currently, around a third of this air escapes through leaks, causing not only energy losses and increased costs in production processes, but also malfunctions in the relevant machinery and plant. The OmniSent system is designed to provide continuous monitoring without disrupting production, as well as to detect leaks in real time, pinpoint their location accurately, be energy-efficient and cost-effective, and operate reliably even in challenging industrial environments. The iHub project addressed two key challenges in this regard: wireless technologies for data transmission from Fraunhofer IIS/EAS and algorithms for local pre-processing from IMMS.

The IMMS solution: Algorithms for local pre-processing

IMMS has investigated and optimised signal processing algorithms on sensor nodes to meet the following requirements: feature extraction from high-sampling-rate ultrasonic signals (temporal and spectral features), energy-efficient implementation on resource-constrained microcontrollers, low inference time for real-time classification, and robustness against background noise. Techniques such as classical signal processing methods (FFT, statistical features), decision trees and random forests, as well as deep neural networks combined with optimisation techniques such as quantisation, were investigated. The focus was on the development and optimisation of signal processing algorithms to be implemented on the sensor nodes – which is crucial for the efficiency of the overall system: intelligent local processing significantly reduces energy consumption and data transmission volume.

The research led to a clear and practically applicable finding: traditional machine learning models, specifically decision trees and random forests, are ideally suited to local signal processing on resource-constrained sensor nodes. These models offer an excellent balance between several critical requirements. They achieve extremely low inference times of less than 30 microseconds, enabling real-time processing. They require minimal computational resources and therefore consume very little energy, which is crucial for battery-powered sensors. At the same time, they offer high predictive accuracy.

www.imms.de/ihub

IMMS is developing a wireless vibration measurement system for lower-emission concrete block production. Photograph: FlorinBirjoveanu, Pixabay.

Project launch of WirelessAccel* – wireless vibration measurement system for lower-emission concrete block production

Lower-emission concrete production with the same product quality

www.imms.de/wirelessaccel

Concrete, one of the most important building materials, has an enormous carbon footprint. Each tonne of cement, the binding agent in concrete, produces 587 kg of CO_2 equivalent. Every year, 27.5 million tonnes of cement are consumed in Germany and around 4.65 billion tonnes worldwide.

The WirelessAccel project aims to reduce CO_2 emissions in concrete production without compromising product quality. The goal is to develop a system that facilitates the use of more environmentally friendly building materials, such as recycled materials and reduced amounts of cement. Monitoring the manufacturing process is intended to reduce waste and thereby decrease CO_2 emissions.

IMMS will therefore develop a wireless measurement system for recording vibrations throughout the entire vibration system of a concrete block machine. This system should be capable of accurately recording the complex and highly dynamic vibrations that occur during the compaction process in real time, thereby enabling precise monitoring and adjustment of production parameters. This is particularly important for low-cement concrete mixes or recycled materials.

Time-synchronous and energy-efficient data acquisition

To this end, IMMS is researching methods for the precise time synchronisation of up to 12 wireless sensor nodes. This enables synchronous measurement at different locations on the concrete block machine. At the same time, an energy-efficient data transmission protocol is being implemented that reliably transmits the recorded acceleration data to a central gateway in real time at a sampling rate of 2 kHz and a measuring range of up to 500*g*. The sensor nodes are designed to withstand extremely high accelerations while operating with minimal energy consumption, creating a robust, durable measurement infrastructure for this demanding manufacturing process.

www.imms.de/wirelessaccel

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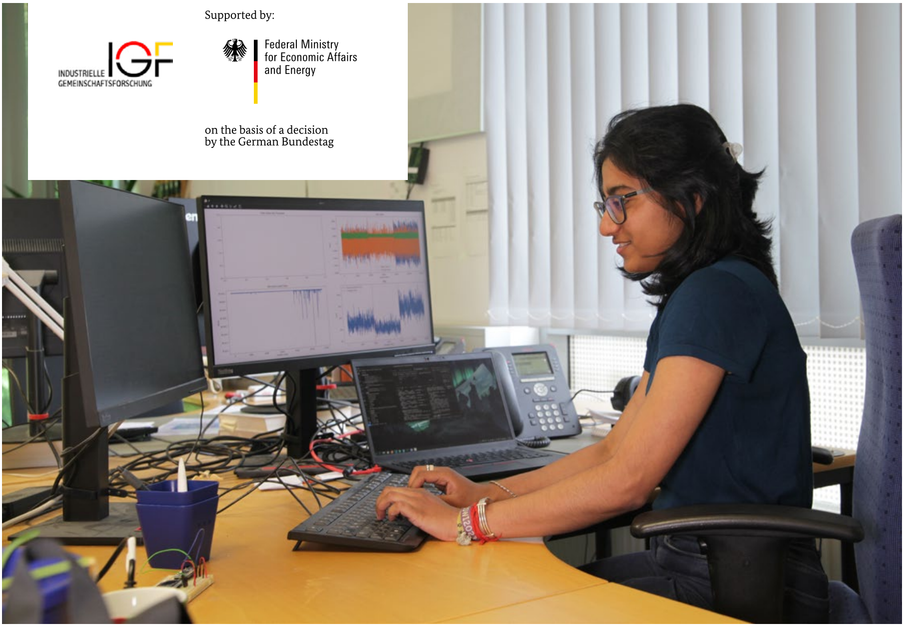


In the SecureTSN project, IMMS is developing the core AI-based anomaly detection component for protecting time-sensitive networks against attacks. Photograph: IMMS.

SecureTSN* project launch: AI-based attack protection for time-sensitive networks

Production downtime and security risks caused by attacks on time-sensitive networks (TSN)

Industry 4.0 applications – ranging from robotics and production lines to distributed sensor networks – require reliable, time-synchronised communications solutions such as TSN. Time-sensitive networks (TSN) operate like a precise clockwork mechanism: All devices on the network have the same understanding of time and follow the same rules for processing and forwarding network packets, as well as for selecting and reserving bandwidth and communications paths. This ensures that every message reaches its destination at exactly the right time. Delays, or so-called latencies, in message transmission are known and are taken into account when synchronising communications.

www.imms.de/realtime

A successful cyber attack on such networks can not only cause production downtime but, depending on the area of application, may also endanger people's safety.

Therefore, IMMS is developing a comprehensive AI-based attack protection system for TSN in the SecureTSN project. The aim is to ensure that this does not reduce production speed without causing any additional overhead.

Insecurity of old stand-alone solutions

Currently, in many cases, heterogeneous fieldbus systems such as PROFINET, EtherCAT, Ethernet/IP, Modbus or CANopen are still used to connect sensors and actuators to an automation device in industrial automation solutions. These systems are part of operational technology (OT) networks, which are usually designed for the long term and are used to control physical processes such as machines, plant or sensors in industry. Many of them are older systems tailored to a specific application.

The resulting isolated networks not only prevent interoperability, but also increase vulnerability to cyber-attacks.

TSN as a solution – protective shield to be further expanded

To counteract this, IT and OT networks are increasingly being converged using time-sensitive networking (TSN). TSN ensures deterministic latencies, guaranteed quality-of-service and high availability. However, a comprehensive security architecture is still lacking.

SecureTSN project strengthens security architecture

The SecureTSN project addresses this gap. The aim is to provide hardware and software extensions that protect TSN networks against deception, manipulation and denial-of-service attacks, in which targets are overloaded. In doing so, the project focuses on the critical TSN functions of time synchronisation (IEEE 802.1AS) and scheduling (IEEE 802.3Qbv).

IMMS is developing the key AI-based anomaly detection component

Within the project, IMMS is working on the development and integration of AI-based attack detection systems into TSN-compatible devices. IMMS utilises its TSN test laboratory and expertise in embedded systems to train machine learning models that detect time-series anomalies – in particular delay attacks – in real time. The models are then optimised for deployment on microcontrollers and edge switches. This compact, hardware-close implementation will be embedded in switches and end devices, enabling them to continuously monitor network traffic, immediately report potential attacks and, where necessary, trigger countermeasures. Through this combination of model training, optimisation and hardware integration, IMMS provides the central anomaly detection component that strengthens the security of the entire TSN infrastructure.

Validation with demonstrator

The results will be validated in a test and demonstration setup that will show the security of TSN switches, end devices and switched end devices under real-world attack conditions. By combining standardised security profiles, hardware security functions and intelligent monitoring software, we are increasing the acceptance of TSN among SMEs, enabling faster time-to-market and strengthening the resilience of industrial manufacturing and automation networks.

www.imms.de/embeddedai

In the thurAI project, IMMS has developed a compact, self-sufficient system for continuous particulate matter monitoring that can be integrated into existing infrastructure, and has installed it for measurements in Ilmenau's holiday resorts.

Photograph: IMMS.

Smart city solutions expanded in Ilmenau

The smart city solutions developed as part of the thurAI* project – a collaboration between Ilmenau City Council, Technische Universität Ilmenau and IMMS – were expanded in 2025. The aim was to use digital technologies in such a way as to make citizens' everyday lives easier in practical terms and to make local government processes more efficient.

www.imms.de/thurai

Real-time information is at the heart of digital services for everyday life. Visitors to the swimming and ice skating halls can check current occupancy levels online and plan their visits more effectively. A smart street lighting monitoring system ensures that faults are automatically detected and rectified more quickly – boosting both safety and energy efficiency. For environmental and climate data, a network of monitoring stations continuously records particulate matter, temperature, humidity and other weather data. This information is processed via the city's web portal, made openly available and can be used by residents, the local authority and researchers. A new addition is the real-time measurement of the Ilm river level, which enables earlier detection of potential flooding. In addition, the city is testing a visual sensor system that automatically detects and reports available parking lots. The aim is to reduce traffic caused by people searching for parking spaces and to improve traffic flow in the long term.

ilmenau.de/smartcity

Since 2025, the information has been available at **www.ilmenau.de/smartcity**. Overall, Ilmenau demonstrates how a medium-sized town is gradually transforming into a smart city through targeted partnerships and practical digital solutions – with clear benefits for the public, the local authority and the research community.

Using self-sufficient modular sensor systems such as this one, IMMS has supported, amongst other things, the monitoring of microclimate and drought stress at eleven crop production sites in central Germany as part of the six-year EXPRESS experimental field. Photograph: IMMS.

Project completion of EXPRESS* – self-sufficient, modular sensor systems offering cost-effective options for data collection in agriculture

Regional Experimental Field EXPRESS

As part of the Central German experimental field EXPRESS, IMMS has successfully completed its work in the project on data-driven networking and digitalisation in agriculture (EXPRESS) after six years.

www.imms.de/express

As part of the EXPRESS project, led by the Institute for Business Informatics at Leipzig University, the Helmholtz Centre for Environmental Research GmbH – UFZ, the Fraunhofer Centre for International Management and Knowledge Economy IMW (later the Fraunhofer Institute for Systems and Innovation Research ISI) and IMMS worked on the fundamentals of how existing technical infrastructures interact with new technologies and methods on agricultural holdings.

The background to this was the growing importance of digitalisation in agriculture, for example to optimise the irrigation of crops during long dry spells. However, many farms lacked the necessary resources to identify suitable and affordable systems, understand their capabilities and derive benefits from them.

EXPRESS was primarily aimed at crop production, with a particular focus on specialised crops. Digital technologies were intended to increase resource efficiency in this sector, support environmentally friendly production and preserve biodiversity in the long term. Innovative technologies such as sensor technology, blockchain, virtual reality, field robots and 5G applications were used to help shape new value chains and optimise production processes. As part of the EXPRESS project, potentially suitable technologies were tested in collaboration with farmers using five use cases and presented to the industry:

- cross-scale water stress monitoring for irrigation optimisation
- automatic monitoring of abiotic key parameters, e.g. by measuring the microclimate in the crop
- food tracing via block chain
- augmented/virtual/mixed reality in agriculture
- data integration and management of highly heterogeneous data sources from various sensor systems

IMMS supported monitoring of microclimate and drought stress

IMMS was responsible for data collection and for determining the microclimate and other parameters for monitoring drought stress. As part of this, various system solutions for these applications were presented to agricultural businesses. In addition, IMMS tested various sensor systems available on the market to assess their suitability. Furthermore, IMMS equipped the experimental fields with suitable sensor technology, monitored their operation and the transmission of data.

www.imms.de/monitoring

IMMS developed cost-effective, self-sufficient sensor systems for practical use

The focus of the IMMS developments was on practical, self-sufficient sensor systems. These were designed to be as modular as possible so that they could be adapted to the specific conditions on a farm and used there for further analysis and optimisation. The challenge was to develop cost-effective systems that could measure all

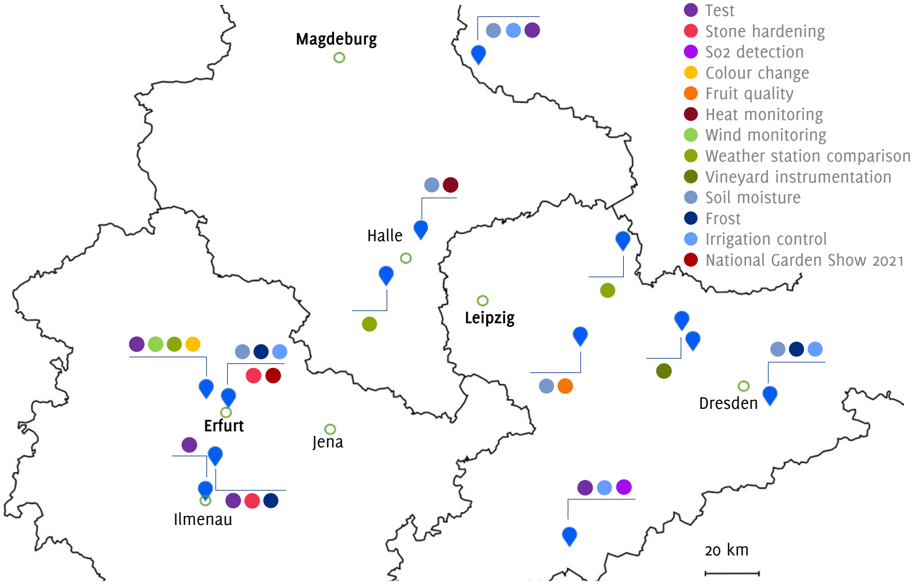


Figure 1: Overview of the field tests carried out in EXPRESS to evaluate various sensor applications. Graphic: IMMS.

the necessary parameters with sufficient accuracy whilst, at the same time, enabling meaningful and, above all, useful insights to be drawn from as few measurement points as possible.

Six years of field studies in collaboration with farmers in central Germany

Over the past few years, IMMS has used digital technologies to help farmers in the German federal provinces Thüringen, Sachsen and Sachsen-Anhalt address their concerns at various locations.

As part of the project, experiments and trials were carried out at 11 different locations in central Germany, in collaboration with partners from the fields of testing, research and end-users, to demonstrate the benefits of digital technologies.

www.imms.de/express

Figure 1 shows the locations where various sensor technologies were tested and where solutions to specific issues raised by the partners were developed and evaluated. This work incorporated parameters relating to topics such as the detection of bud growth in spring, as well as the stone-hardening phase and colour change in cherries, frost monitoring, heat monitoring under a roof, the comparison of soil moisture sensors, and the influence of soil cultivation on fruit quality.

Figure 2: Research into heat monitoring under a roof (left) and the colour change in cherries (right). Photographs: IMMS.

The result was a new modular sensor platform (see Figure 3) for data collection in agricultural and forestry contexts, which continues to be used at various locations for research in the follow-up and sister projects EXPRESS.smart! and MIRO. Various technologies such as MiraMesh, LoRaWAN or Bluetooth are used for communications in the sensor network, depending on the specific application. The sensor nodes transmit their measured values to a gateway, which temporarily stores the data, assigns measurement points to them and creates local log files. Every hour, the data is transmitted via a mobile network to a server, where it is written to a time-series database (InfluxDB) and visualised in dashboards (Grafana). This system also allows thresholds to be set and, where necessary, alerts to be sent via various channels. Furthermore, the system can monitor failures, enabling rapid resolution. Analysis scripts on the server process the data and write the analysis results back to the database, from where they can be visualised, alongside the raw data where appropriate.

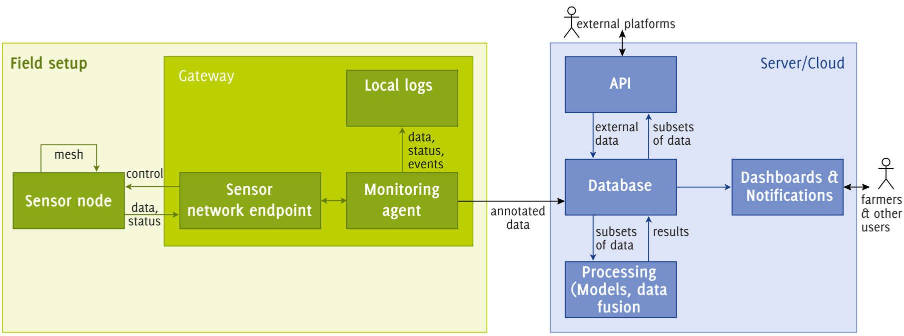


Figure 3: Sensor platform for data collection and processing. Graphic: IMMS.

Figure 4: This dendrometer, developed in various versions as part of the EXPRESS project at IMMS, was used to monitor bud growth (top left) and the stone-hardening phase in cherries (top right), to monitor bud growth in the context of late frosts (bottom left), and for studies into the influence of soil cultivation on fruit quality (bottom right). Photograph: IMMS.

Development of a dendrometer

One of the sensors developed as part of the project is a dendrometer, which can be connected to the sensor platform and used for various purposes; see Figure 4. Various sizes were created for this purpose and used as a bud dendrometer, as a gauge for detecting stone hardening in sweet cherries, and as a fruit dendrometer. With the help of this dendrometer, it is now possible for the first time to continuously and digitally track and quantify the developmental stages at the start of the season with minimal staffing requirements. This represents a major step forward for farmers in terms of assessing a cultivar in relation to climate change.

In addition, numerous small-scale experiments were carried out during the six-year duration of the project, such as:

- Camera-based detection of developmental stages in apples
- Radio-based irrigation control
- Drought stress sensors
- Evaluation of RFID sensors in agriculture
- Testing of a sensor system for measuring leaf pressure
- Testing of wireless sensors in vegetable cultivation (cabbage)
- Measurement campaigns to determine range and their evaluation

Figure 5:

Comparison of soil moisture sensors.

Photograph: IMMS.

All activities were carried out in close collaboration with the project partners (IMW/ ISI, ULE, UFZ) and user partners (LVG, JKI), and have significantly raised the profile of EXPRESS at regional and national levels; see: www.digitalisierung-landwirtschaft.de/veranstaltungen/.

digitalisierung-landwirtschaft.de/veranstaltungen

Digitalisation is becoming increasingly important in agriculture too, for example to optimise the irrigation of crops during long dry spells. However, many farms lacked the necessary resources to identify suitable and affordable systems, understand their capabilities and derive benefits from them. The EXPRESS project has made a valuable contribution to changing this.

www.imms.de/express

At the 2025 Pome Fruit Day at the Teaching and Research Centre for Horticulture and Arboriculture (LVGA) in Müncheberg, the sensor technology developed by EXPRESS for monitoring abiotic parameters and the automated irrigation control system were presented. Photograph: IMMS.

EXPRESS* and MIRO* projects: IMMS presents digitalisation solutions for fruit growing

IMMS presented findings from the two sister projects, EXPRESS (Experimental Field for Data-Driven Networking and Digitalisation in Agriculture) and MIRO (Central German Innovation Region for Fruit Growing), at the 2025 Hazelnut Day event held at the Teaching and Research Centre for Horticulture (LVG) in Erfurt.

www.imms.de/express

A presentation examined predicted climate changes for Central Germany and their implications for the irrigation of fruit trees from the perspective of the MIRO project. This was followed by a demonstration of the automated irrigation control system developed as part of the EXPRESS project on the LVG's trial plots.

www.imms.de/miro

In addition, IMMS joined forces with other research institutions and fruit growers to support the 2025 Pome Fruit Day at the Teaching and Research Centre for Horticulture and Arboriculture (LVGA) in Müncheberg, Brandenburg. The day focused on bringing

At Hazelnut Day 2025 in Erfurt, the installation of soil moisture sensors was among the innovations presented. Photograph: IMMS.

together research, practical application and taste. In a relaxed atmosphere, visitors were able to listen to talks by experts on current developments in apple cultivation and related fields, and learn more at the stands about, for example, the possibilities of digitalisation in fruit growing.

Two of the solutions developed by EXPRESS were showcased at the exhibition stand: sensor technology for monitoring abiotic parameters and an automated irrigation control system.

Wireless temperature measurement on fruit trees. In EXPRESS.smart, numerous such measurement points are installed across a fruit-growing area to determine its specific climatic characteristics. Photograph: IMMS.

Project start of EXPRESS.smart:* AI-supported climate and crop monitoring in regional fruit and wine growing to safeguard and optimise yield and quality

Predicting the risks posed by late frosts in fruit growing and viticulture

The quantity and quality of the harvest in fruit and wine growing are determined early in the year. It is particularly important whether late frosts occur at the end of the winter season, as these can cause considerable damage to the plants.

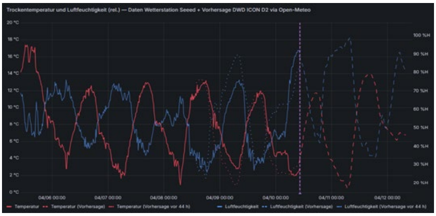
In the EXPRESS.smart project, IMMS is testing digital and AI-based solutions to predict frost events and the resulting risks to the harvest, as a basis for recommendations for action.

Solution: Integrated frost monitoring

To ensure a responsive reaction, specifically identified local conditions – such as terrain profiles and air currents – are used to supplement general weather forecasts, particularly with regard to expected minimum temperatures. At the same time, sensors determine the stage of development in which the plants are and the current temperature. On this basis, tailored algorithms decide whether protective measures need to be taken and, if so, which ones.

IMMS is responsible for the entire data pipeline, from data collection through to the formulation of recommendations for action.

A sensor developed at IMMS to measure bud growth on a cherry tree. In EXPRESS.smart, the bud's size is used to determine its stage of development and, consequently, the risk of frost damage. Photograph: IMMS.



Comparison between general weather forecasts for temperature and humidity and actual measured values. In EXPRESS.smart, the specific climatic characteristics are determined for all measurement points within a fruit-growing area based on the results of this comparison. Source: IMMS.

Innovation: AI-powered data analysis

AI models help to recommend appropriate measures. They analyse the data collected, identify unusual patterns and assess the risks involved. They then suggest suitable countermeasures – such as specific frost protection measures or changes to irrigation strategies. At IMMS, we combine suitable AI algorithms for analysing our sensor data with input from our project partners to provide comprehensive climate and plant monitoring.

Benefits: Knowledge transfer between research and practice

To date, protection and optimisation measures in fruit growing and viticulture have been based primarily on empirical knowledge; they are sometimes unreliable and often require a significant investment of resources. The combination of tailored weather data, automatically determined plant growth stages and AI-supported algorithms makes these tried-and-tested strategies more tangible and accessible to a wider range of practitioners. This means that even smaller farms can benefit from the recommendations and efficiently protect and increase their yields.

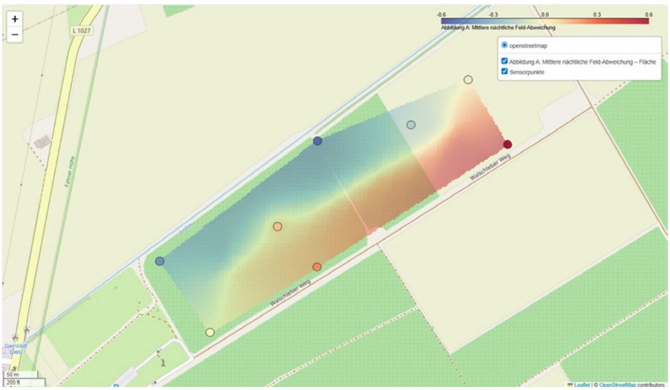


Illustration of the humidity-temperature distribution across a specific sub-area in fruit cultivation. In Express.smart, humidity-temperature sensors measure the temperature distribution within the orchard plot and can thus provide indications of 'cold air spots'. Source: OpenStreetMap/IMMS.

IMMS activities in the "Mittelstand-Digital Zentrum Ilmenau" (SME Digital Centre Ilmenau)*

Events and information for SMEs

In 2025, IMMS was operating as the "Smart Sensor Systems Model Factory" at the "Ilmenau SME Digital Centre", offering a wide range of **events** and information. A total of 24 orientation meetings, 10 regulars' tables, 4 talks, 10 specialist workshops and 6 online seminars were held. The aim of these initiatives was to provide practical support to small and medium-sized enterprises (SMEs) in introducing and implementing digitalisation and AI solutions.

In addition, IMMS presented itself as a model factory at 19 regional events organised by industry networks, as well as at trade fairs. At national level, further 15 activities were carried out as part of the "Mittelstand-Digital" network. The offers go hand in hand with the partners Ilmenau TU, where the office and the "Networking Model Factory" are located, the Ernst Abbe University of Applied Sciences Jena as "Virtualisation Model Factory" and the Gesellschaft für Fertigungstechnik und Entwicklung e.V. in Schmalkalden as "Process Data Model Factory".

www.imms.de/md

The SME Digital Centre Ilmenau focuses on sustainability, platform economics and AI. As "Smart Sensor Systems Model Factory", IMMS is primarily dedicated to the topics of retrofitting, predictive maintenance, smart sensor systems, diagnostic solutions and AI-based sensor data evaluation. For example, retrofit solutions can be provided for machines that automatically record and visualise the machine's condition. Another core area of expertise is the practical implementation of smart sensor systems, which can be used to monitor machine tools using artificial intelligence, for example. Demonstrators also show digital diagnostic solutions that use mobile measuring devices to find cost-intensive leaks in compressed air systems, for example. The AI trainers of all SME Digital Centre Ilmenau partners deal with SME issues relating to the use of AI.

www.imms.de/i40

Parallel to the events, 8 **publications** were produced, e.g. on cooperation with companies in projects or on demonstrators, which are distributed to interested parties on the centre's website, via newsletters and social media.

IMMS has implemented active monitoring of the compressed air system in its laboratories. This ensures reliable operation of the system and triggers an alarm in the event of a fault, such as a bursting connection hose. The demonstration solution is regularly showcased at the centre's events. Photograph: IMMS.

New digitalisation projects

In addition to the various events, the "Model Factory Smart Sensor Systems" at IMMS also worked on two demonstration and implementation projects described below, which demonstrate possible applications of artificial intelligence (AI) in manufacturing SMEs.

www.imms.de/md

Expansion of the 'Stationary Compressed Air Monitoring' demonstrator

As part of the work carried out at the Ilmenau SME Digital Centre, an active monitoring system for the compressed air system was implemented in the IMMS laboratories as a demonstration solution. On the one hand, this serves to ensure reliable system operation and to trigger an alarm in the event of a fault, such as a burst connection hose. On the other hand, the demonstrator is an integral part of the demonstrations held at the Centre's events. Those interested can experience first-hand how the system works and see possible responses, such as push notifications.

www.imms.de/i40

Due to increased demands on research work at IMMS, it became necessary to dampen the vibration-isolated foundations in the main laboratory of the Mechatronics department with significantly greater precision. To this end, the previous passive, spring-based vibration isolation was replaced by active vibration isolation systems, which also utilise compressed air. This conversion made it necessary to re-collect compressed air consumption data to enable the active compressed air monitoring system to be re-calibrated. As numerous influencing parameters from different laboratory areas must be taken into account during data collection, this process takes a very long time and continues into the first half of 2026. The data obtained forms the basis for an AI-based analysis of measurement data, which continuously learns and thus enables increasingly precise responses to changes.

AI application project: 'AI-based internal knowledge management for SMEs'

It is clear from numerous discussions with SMEs in Thüringen that the recording and sharing of in-house knowledge is of great importance. Knowledge management covers both explicit knowledge derived from documents, ERP and other planning systems, and from operational processes, as well as implicit knowledge in the form of employees' know-how and experience. This knowledge is often lost when skilled staff leave the company.

The aim of the project is to make organisational knowledge accessible via a simple query in a chat-like user interface, thereby enabling low-threshold, natural-language access. The technical foundation is provided by artificial intelligence in the form of large language models (LLMs), which are enriched with company-specific data whilst taking data protection considerations into account (Retrieval Augmented Generation, RAG). In this way, the strengths of traditional query-based systems are combined with generative AI models.

Implementation can take place either via a secure cloud instance with access to a dedicated third-party LLM instance, or via an LLM installed locally on the organisation's own high-performance server (on-premises). The choice of the appropriate implementation option is made on a project-specific basis, depending on the size of the company's data pool, the requirements for processing speed, and taking into account procurement, installation, licensing and maintenance costs. Regardless of the option chosen, both require a web-based front end that enables both the simple entry of new data sets and the process-oriented retrieval of corporate knowledge.

In collaboration with the Ilmenau-based company deenovum AG, the project developed a versatile solution for in-house knowledge management based on available AI and internet technologies. The application scenario covers a wide range of business processes – from onboarding new specialist staff and supporting customer service to providing specific assistance with the development of new products and services in SMEs. The implementation of sample data for demonstration purposes for 'Mittelstand-Digital' activities, as well as comprehensive testing of the system, takes place in the first quarter of 2026.

Networking with digitalisation stakeholders expanded

Another important part of the work at the SME Digital Centre Ilmenau is the networking with stakeholders involved in the digital transformation of companies. There was a regular exchange of ideas in the nationwide ´Mittelstand-Digital´ Network, including in topic-specific working groups or at regional conferences of the participating centres. Topics included the needs of companies and the expansion and target group-orientated design of support services. IMMS also regularly exchanged information with Thuringian networks and initiatives, such as the Cross-Cluster-Initiative Thüringen (CCIT), the Cluster for Electronic Measurement an Device Technology in Thuringia (ELMUG eG), the Thuringian Centre for Mechanical Engineering (ThZM), the Industry Association of the Plastics Industry (PolymerMat e.V.), the Thuringian Centre for Learning Systems and Robotics (TZLR) and the Association of Thuringian AI-Transfer Centres.

www.imms.de/md

In addition, the SME Digital Centre Ilmenau, together with the one in Chemnitz, the ScaDS.AI Dresden/Leipzig and other partners form the AI Hub Saxony-Thuringia. The AI Hub is dedicated to transferring the results of basic AI research from ScaDS.AI and its partners via the Mittelstand-Digital Innovation Hubs to companies. At the same time, the SME Digital Centres bundle the requirements of SMEs so that these are taken into account in basic and applied research.

digitalzentrum-chemnitz.de

scads.ai

ki-hub-sachsen-thueringen.de

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Mittelstand-Digital

Mittelstand-Digital Zentrum Ilmenau

AI-based optimisation of injection moulding processes

In the ProQuaOpt project, AI-based methods were developed for the automated optimisation of productivity and quality in injection moulding processes. For the mould used, this reduced the cycle time by approximately 4 seconds, which increased daily productivity by 73 products, or approximately 5 per cent. Photograph: IMMS.

Motivation and overview

Injection moulding is the most widely used process for manufacturing plastic parts across virtually all application areas. In Germany, 14.6 million tonnes of plastic are processed annually by approximately 3000 companies into moulded components and assemblies it with wide variety of finished products, made from up to four materials, generating revenues of € 65.1 billion. The resulting products range from individual moulded components to complete assemblies. They may consist of up to four different materials and often feature complex free-form surfaces that can be finished with various surface textures (from grained to glossy). If the waste rate of such parts and assemblies could be reduced by just 1% from the current 4%, approximately 150,000 tons of plastic and approximately € 650 million in costs would be saved in Germany alone.

www.imms.de/i40

Injection moulding machines are typically configured by skilled personnel to produce high-quality parts. However, producing good parts alone does not automatically ensure resource-efficient manufacturing. The optimum balance of high quality, high throughput, and minimal resource input can currently only be identified through iterative trial-and-error procedure. A considerable saving potential could be achieved by development of tools that reduce the production of rejected parts. In addition, further reductions in material consumption, energy usage, and production time per part could be achieved if the optimal operating point is identified. The effectiveness of the processes and the quality of the products could be continuously evaluated and optimised accordingly.

In the ProQuaOpt project, one such tool is developed using AI-based approach for automated productivity and quality optimisation of the injection moulding processes. To achieve this, a product-process-quality closed-loop control system was established. The system consists of a controlled process at the injection moulding machine, a measurement unit for optical quality inspection of the component, and a controller in the form of a self-learning assistance system.

The combined system was implemented at the project partner KHW Kunststoff- und Holzverarbeitungswerk GmbH and refined through iterative testing. The project demonstrated that the integrated framework can refine process parameter candidates under real production conditions. The AI-based surrogate model predictions validates the process parameter combination and reliably control the injection moulding process toward improved quality and reduced cycle times. The optimisation of cycle time varies depending on the mould used and other additional process parameters and can therefore only be evaluated for the respective product. The mould used at KHW, the cycle time for the production of the part was reduced by approximately 4 seconds using the implemented optimisation process. This corresponds to an increase in daily productivity of 73 additional products, or roughly 5% increase. If errors occurred during optimisation, the system automatically returned to the last acceptable solution, thereby ensuring uninterrupted operation while simultaneously reducing the number of required physical machine trials.

From manual adjustment to closed-loop control – approaches and challenges

Using the closed-loop control system, the injection moulding machine can operate continuously at an optimal production point with respect to productivity, quality, and energy efficiency. Traditionally, machine settings are optimised manually step by step, to produce a product with no defects. Further, operators must decide whether additional adjustments and fine-tuning of parameters are worth the extra time required, even after the produced parts already meet the quality requirements. In contrast, the optimisation system continuously improves and adjusts the process parameters in small iterative steps to reach an optimal operating point. The system

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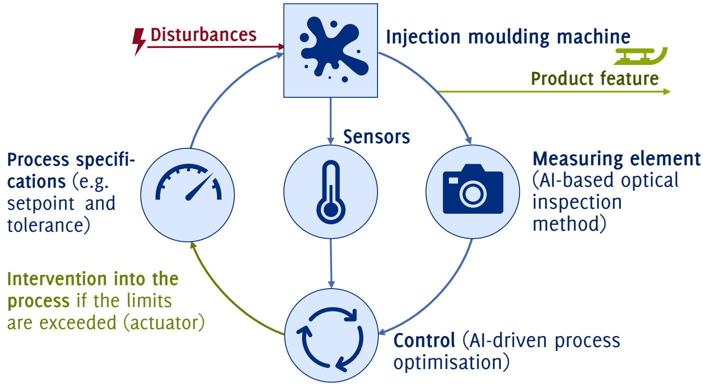

Figure 1:

Product-process-quality control loop.

Graphic: IMMS.

can also start with previously stored parameter settings for a specific mould-machine combination.

Injection moulding machines are already equipped with a large number of sensors that continuously record machine and process data. Some of these data, such as oil supply temperature or ejector stroke, are essential for stable machine operation but do not directly affect part quality or the duration of the injection moulding cycle. In addition, injection moulding processes can be characterised using a wide range of process parameters, including cylinder temperature zones, melt pressure, injection speed, injection volume flow rate, back pressure, screw rotation speed during plasticising, injection stroke, residual melt cushion, holding pressure, holding pressure time, residual cooling time, clamping force, and mould wall temperature. A key challenge of the project was therefore to identify which parameters significantly influence the process and to distinguish these relevant factors from noise and other disturbance variables within the machine data. In particular, the relationships between the recorded process data and the three main target criteria, product quality, cycle time, and energy consumption, had to be analysed and quantified.

Product–process–quality control loop

The implemented product–process–quality control loop combines quality information extracted from image data with process data from the injection moulding machine. Based on these inputs as feedback to the optimisation process, it generates recommendations for the adjustment of the process parameters for the injection moulding machine. At present, however, the new parameter settings still need to be entered manually on the machine, as write access via a digital interface is not available on the equipment used.

IMMS developed the controller for this closed-loop system in the form of an AI-based process optimisation module. It receives feedback from the quality control unit providing information on product quality. It further explores the process parameter space, and identifies potential solutions for optimising multiple objectives such as cycle time, energy consumption, and material usage. Based on this analysis, it generates recommended parameter settings for the injection moulding process. In addition, IMMS was responsible for designing and implementing the interfaces to the injection moulding machines, as well as for the data storage and data preprocessing infrastructure.

Interfaces for data acquisition, real-time monitoring, and extensibility

To achieve a highly generic solution, IMMS analysed the interfaces of injection moulding machines in collaboration with machine manufacturers and developed a data acquisition concept. This was consolidated into an integrated system architecture that combines machine data acquisition, data processing, and quality evaluation within a unified workflow. This enables continuous acquisition of machine data, integration of quality information from image-based inspection, and centralised storage and processing of all relevant data. The modular architecture allows different data sources and interfaces to be integrated without modifying the core processing pipeline.

With this system, machine and quality data can be processed, analysed, and fed back during operation in near real time. This provides the basis for real-time monitoring and parameter evaluation, which was successfully demonstrated in live setups at the partner KHW.

In addition, the architecture supports seamless integration of additional data sources, such as OPC UA-based time-series data and image-based quality measurements, and provides standardised interfaces for downstream analysis modules. This ensures that the system can be further extended in the future toward closed-loop control and data-driven process optimisation.

AI-based controller with surrogate modelling and evolutionary optimisation

Based on the available data, IMMS investigated optimisation algorithms and implemented **surrogate modelling** approaches to approximate the relationship between process parameters and resulting product quality. Surrogate modelling (also referred

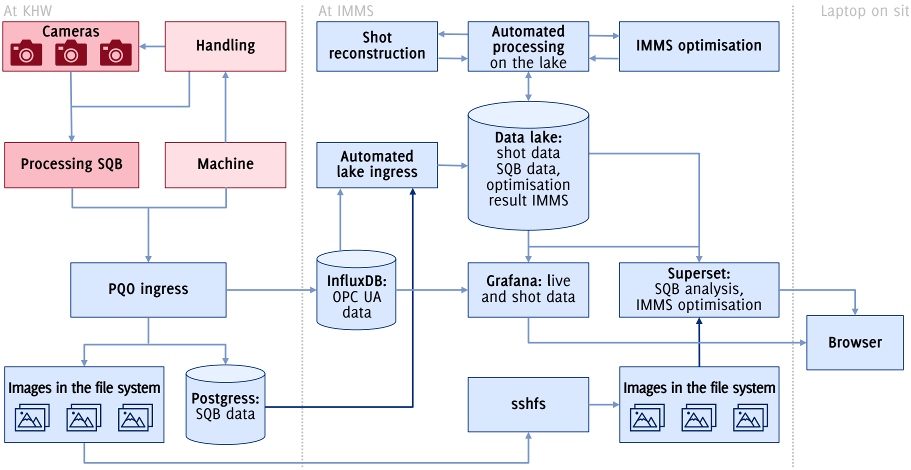

Figure 2: Data acquisition workflow module of the AI-based injection moulding optimisation demonstrator implemented at the KHW partner site; red: Steinbeis Quality Assurance and Image Processing GmbH (SQB), blue: IMMS. Graphic: IMMS.

to as meta modelling) describes approaches in which expensive or computationally complex models are replaced by simpler, computationally efficient approximations. The goal is to accelerate or simplify simulation, optimisation, and inference tasks. These approaches are particularly useful in high-dimensional and complex parameter spaces. However, their performance strongly depends on the quality and representativeness of the training data, the choice of surrogate model, and the tuning of hyperparameters. As a result, significant domain expertise is required to minimise model errors and ensure reliable predictions. Appropriate surrogate models were selected and trained at IMMS, using injection moulding process data, and thereby enabled efficient AI-based evaluation of candidate parameter configurations without the need for time-consuming physical machine trials.

Building on these models, IMMS implemented **evolutionary optimisation** strategies, in particular **genetic algorithms**, to search for improved parameter configurations within the multidimensional injection moulding parameter space. These stochastic search methods, inspired by natural evolution, iteratively improve solutions through genetic operators such as mutation, recombination, and selection until an optimal or near-optimal solution is identified. This approach is particularly well suited for complex optimisation problems, as it does not require explicit mathematical models

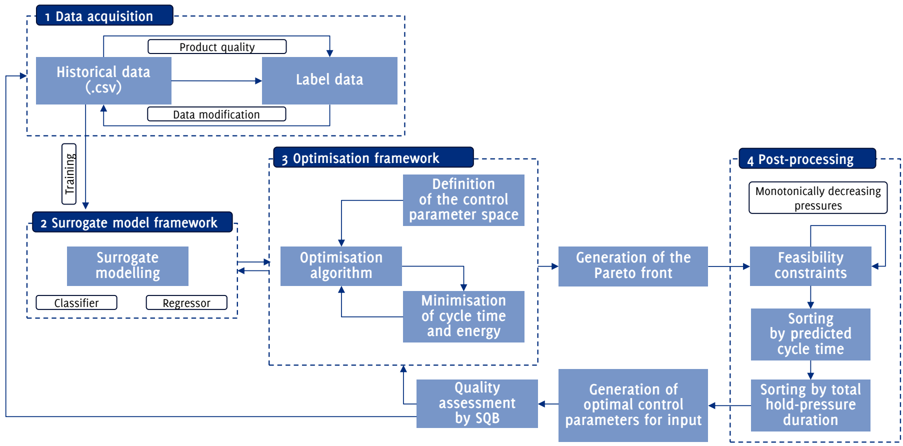

Figure 3: The implemented prototype system is structured as a modular software architecture consisting of four main functional modules.: 1) Data acquisition, 2) Surrogate model framework, 3) Optimisation framework, 4) Post-processing. Grapic: IMMS.

and can operate as a black-box optimisation method. It is especially effective for non-linear, multi-modal, and non-differentiable problems. However, its successful application requires careful parameterisation, since evolutionary algorithms are often computationally intensive, may be difficult to scale, and can exhibit unpredictable convergence behaviour.

The optimisation process implemented in ProQuaOpt evaluates the generated candidate solutions based on surrogate model predictions, iteratively refining the parameter configurations, within predefined bounds set for each controllable process parameters. Measured cycle time, energy consumption, and defect outcomes are fed back into the surrogate models to converge toward optimal production settings.

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Prototype: demonstration of the solution in ongoing production

For the demonstrator at the company KHW, IMMS developed an integrated system architecture that combines machine data acquisition, data processing, and quality evaluation within a unified workflow (see Figure 3). The optical quality inspection implemented by the partner Steinbeis Quality Assurance and Image Processing GmbH (SQB GmbH), shown in red in the figure 2, provides feedback on the injection-moulded parts ejected from the machine to the IMMS control system.

For the machines available at KHW, it was necessary to reconstruct discrete injection moulding cycles from the available time-series data, as the machines did not provide direct cycle segmentation.

The described approaches were implemented in a prototype system with a modular software architecture, as illustrated in Figure 3, consisting of four main functional modules:

1. **Data acquisition:** This module captures process parameters and production data from the injection moulding machines.
2. **Surrogate model framework:** This is a machine learning model, which approximates the relationship between process parameters and resulting product quality. It enables fast evaluation of candidate parameter configurations without requiring physical experiments for each combination and continuously updates from the new data available from both the machines and quality inspection systems.
3. **Optimisation framework:** The prototype uses a genetic algorithm as the main optimisation strategy. The algorithm iteratively generates new parameter configurations, evaluates them using the surrogate models, and identifies improved solutions over multiple generations. This module supports multi-objective optimisation to balance different quality and process-related objectives.
4. **Post-processing:** This module interprets the optimisation results and proposes final machine settings. The demonstrator at KHW includes a fully automated, knowledge-based post-processing system that integrates surrogate model predictions, optimisation results, and quality feedback to automatically determine optimal machine configurations.

Outlook

The prototype demonstrates that process optimisation using machine learning methods is also feasible with limited data. The achieved productivity improvement of 5% was validated for a specific product, using the corresponding tooling on a suitable machine setup. In general, cycle time optimisation depends strongly on the mould, the machine, and various additional process parameters, and therefore can only be specified for the respective product configuration.

IMMS aims to further develop the approach and generalise it across different tools and manufacturing processes. In addition, there is potential to transfer the method to similar optimisation problems beyond injection moulding, particularly to processes where parameter sets influence production outcomes across different machines and where the correct combination of parameters is critical for achieving high product quality and energy-efficient operation.

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Reference:

Real-Time Optimal Parameter Recommendation for Injection Molding Machines Using AI with Limited Dataset, Bipasha Roy. Silvia, Krug. Tino Hutschenreuther. *AI 2026, 7, no. 2: 49.* **https://doi.org/10.3390/ai7020049**

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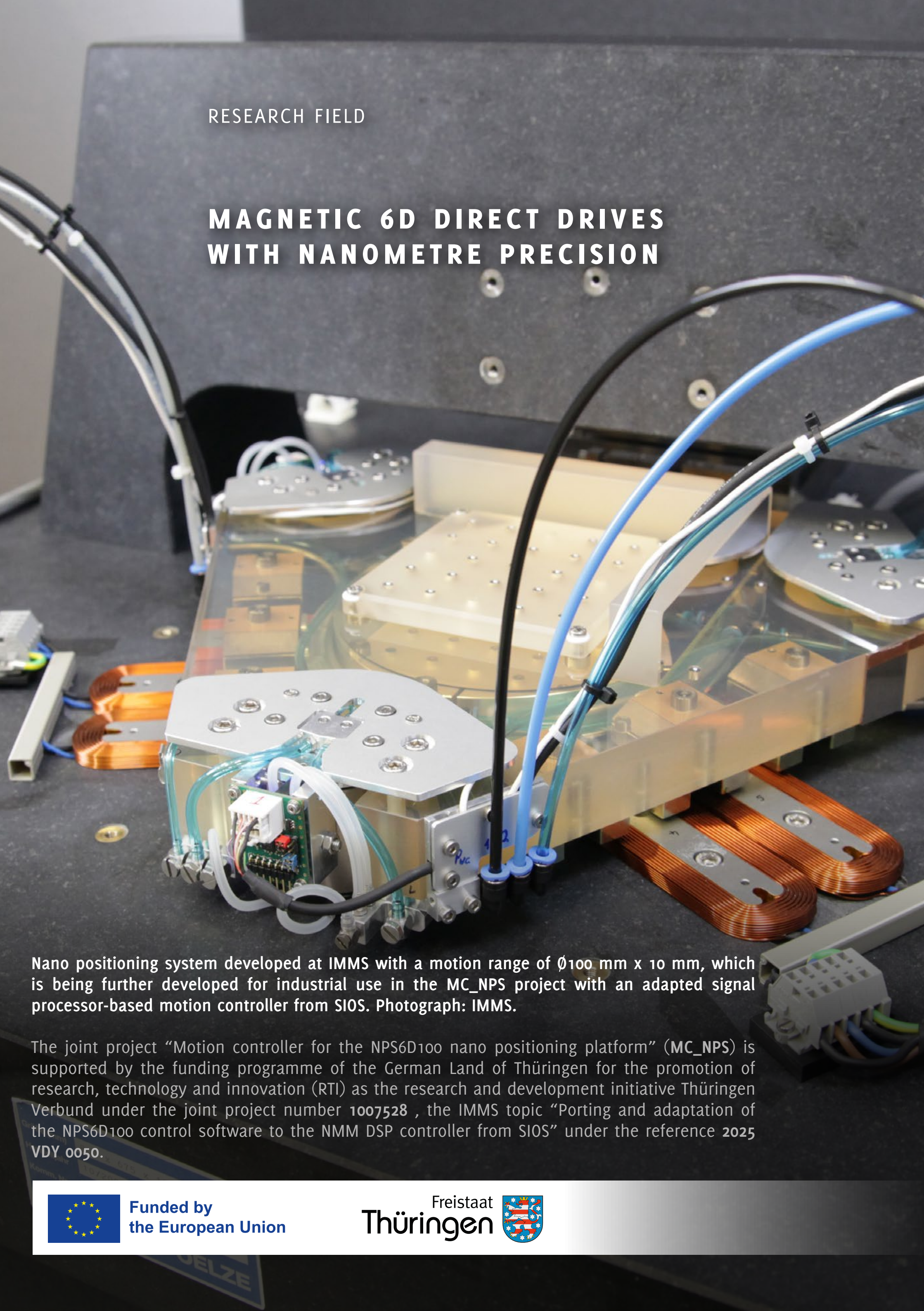
RESEARCH FIELD

MAGNETIC 6D DIRECT DRIVES WITH NANOMETRE PRECISION



Nano positioning system developed at IMMS with a motion range of Ø100 mm x 10 mm, which is being further developed for industrial use in the MC_NPS project with an adapted signal processor-based motion controller from SIOS. Photograph: IMMS.

The joint project “Motion controller for the NPS6D100 nano positioning platform” (**MC_NPS**) is supported by the funding programme of the German Land of Thüringen for the promotion of research, technology and innovation (RTI) as the research and development initiative Thüringen Verbund under the joint project number **1007528** , the IMMS topic “Porting and adaptation of the NPS6D100 control software to the NMM DSP controller from SIOS” under the reference **2025 VDY 0050**.

Funded by the European Union

Freistaat Thüringen

Research field

Magnetic 6D direct drives with nanometre precision

The continuous reduction in the size of the structural elements of technical products in many different sectors increases the demand for precision machinery with which tiniest structures and objects can be measured and manufactured with high accuracy. There are many such objects having spatial extents from millimetres to centimetres, while surface characteristics and functional elements are just a few microns or nanometres in size and have to be positioned with a precision less than one nanometre in the production process.

To blaze the trail for the manufacturing of components from the macro-world with the precision that is associated with the micro- and nano-world, we conduct research on the scientific fundamentals and technical solutions to implement nano-positioning systems acting over long distances of travel. Our highly dynamic integrated multi-coordinate drives move objects with the same accuracy over distances of several hundred millimetres within the shortest time. Our solutions are intended for use under vacuum, in cleanrooms and sites with particular requirements for thermal insulation and elimination of vibrations.

www.imms.de/nmdrives

Highlights of 2025 in our research on magnetic 6D direct drives with nanometre precision

New MC_NPS* project combines expertise from research and industry to achieve nanometre-precise positioning for high-tech applications

On 5 November 2025, SIOS Meßtechnik GmbH and IMMS started the one-year joint project ‘Motion Controller for the NPS6D100 Nano Positioning Platform’ (MC_NPS) at a kick-off meeting at IMMS Ilmenau. The project involves adapting a special control system from SIOS to a nanometre-precise positioning system with a large range of motion developed at IMMS. The aim is to use this combination to develop a market-ready high-tech product for new applications. These range from the semiconductor and optics industries to calibration and verification, medicine, aerospace technology and the future markets of photonics and quantum technology.

www.imms.de/mcnps

Representatives of SIOS and IMMS, partners in the MC_NPS project, at the kick-off meeting on 5 November 2025 in Ilmenau. Photograph: Rolf Peukert, IMMS.

Tiniest structures in a vast field

Many industrial sectors require increasingly precise machines that can measure and process the smallest structures and objects with high accuracy, usually to further miniaturise technical products. Many such objects are a few millimetres to centimetres in size. However, surface features and functional elements often measure only a few micrometres or nanometres. In production, they must be positioned with an accuracy of a few nanometres, i.e. about one millionth of their size. Not only the precision of the drives needs to be improved, but their working range also allows for more applications and, last but not least, greater cost-effectiveness, the larger it can be with the same positioning accuracy.

Individual solutions for research and industry so far

IMMS addresses precisely these requirements with its research, thereby helping to define the current state of the art worldwide: it has developed the NPS6D100 nanopositioning system, which positions objects weighing up to two kilograms within a motion range of 100 millimetres in diameter and 10 millimetres in height with a resolution of less than 2 nanometres and with 6 controlled degrees of freedom. Translated into more everyday dimensions, this would be comparable to a helicopter that can drop its load within a radius of 100 kilometres with an accuracy of less than 2 millimetres.

To open up this system for flexible industrial applications and thus for marketing, it still needs to be connected to the hardware and software commonly used for control in this field. The control hardware has to process the complex control algorithms in real time. The software must allow intuitive operation and flexible integration of different applications. None of this can be achieved with commercially available standard axis controllers.

SIOS already has industrially established and mature hardware and software for controlling its NMM-1 nanopositioning and nanomeasuring machine for such requirements. SIOS is the global market leader with the NMM-1 system. However, this control system cannot be used directly to operate the IMMS drive, as it is designed for a different drive architecture.

Industrial-grade modular complete system for wide applicability

In the MC_NPS project, SIOS and IMMS will work on a marketable solution that combines IMMS' newly researched drive with SIOS' industry-proven control system. The intended result is a system that not only covers a significantly larger working range than SIOS' current leading product, but is also modularly configurable and can therefore work with various probing systems such as focus sensors, atomic force microscopes or microprobes in different applications.

To achieve this goal, SIOS will coordinate the project and adapt and expand the motion controller of its NMM-1 machine, which is based on a special digital signal processor, for the IMMS NPS6D100 drive. On the IMMS side, the control and regulation algorithms developed for its NPS6D100 drive, which enable nanometre-level positioning, will be restructured to match the SIOS control system and finally will be ported to it.

If this fusion of ultra-precise positioning systems, efficient and cost-effective controller hardware and state-of-the-art measuring systems proves successful, it will pave the way for the marketing of the NPS6D100 as another nanopositioning system 'Made in Thüringen' that sets global standards.

www.imms.de/mcnps

The partners of MetraLabs and IMMS at the kick-off meeting of the ERA-AMR project on 14.01.2025. In ERA-AMR, optimised drive systems for autonomous mobile robots are being developed. Photograph: IMMS.

ERA-AMR* project completion – optimised drive systems for autonomous mobile robots

The aim of the one-year ERA-AMR project, which was completed at the end of 2026, was to develop new drive solutions for autonomous robots across a wide range of tasks, thereby enabling innovative production-related applications. A key aspect of this was the development of a software-based modelling tool.

www.imms.de/eraamr

Autonomous mobile robots as assistants

Robotic systems can relieve workers of monotonous and repetitive tasks, especially in the industrial and service sectors, freeing them up for more demanding and varied tasks and increasing overall effectiveness and productivity.

Commercially available autonomous robots on the market are capable of moving forwards, backwards and around bends with simple drives and can turn on the spot. In this way, they already contribute to an efficient material flow and smooth goods management in production and storage areas. They can not only transport goods, e.g. small load carriers for dynamically customisable production lines, but also record data, e.g. for quality assurance or autonomous inventories.

Versatility of assistant assignments limited

For a number of applications, systems with simple drives quickly reach their limits, such as with high loads or certain movements. Sideways movements or manoeuvring out of tight spaces, for example, are not possible.

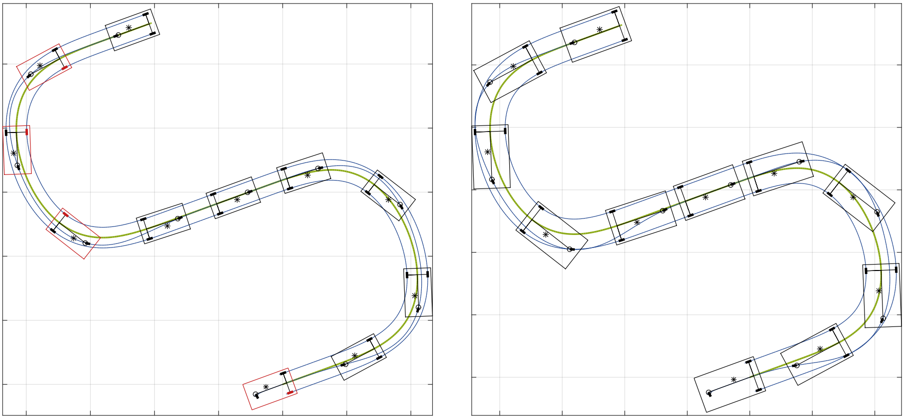
More complex solutions for more flexible movements are more challenging to develop and therefore significantly more expensive. The reason for this is the drive system, which not only has to be designed, technically dimensioned and integrated into the overall system together with the sensors and control technology for a robust and powerful autonomous robot. Depending on the application, there are also other objectives and individual environmental conditions that need to be taken into account during development.

New applications require optimised drive concepts and software-based modelling tools

Meeting these complex requirements calls not only for advanced drive concepts that make autonomous mobile robots more efficient and cost-effective on the basis of defined performance indicators. To achieve these technological improvements, IMMS has focused primarily on developing a software-based modelling tool. In future, this tool is intended to support the development of such systems as early as the concept phase by calculating performance metrics for defined application and requirement profiles and enabling the selection of suitable solutions.

Mathematical approaches, methods and algorithms relating to kinematics and dynamics were utilised for this purpose; these not only optimise drive systems but also contribute to the development of autonomous control systems. On this basis, these control systems can take into account the previously set objectives – such as maximum speed, minimum energy consumption and high robustness – and implement the control tasks optimally to achieve them.

Using the IMMS' new modelling tool, the partner MetraLabs can develop an optimal drive concept based on all the defined requirements and thereby also produce a prototype for a new autonomous robot.



Comparison of the initial and optimised designs. In the initial design (left), critical conditions along the trajectory are marked in red. The optimised design (right) allows the target trajectory to be followed without difficulty. Graphics: IMMS.

The result is an approach that enables a significant increase in performance compared with conventional drive systems, thereby setting new standards in mobile robotics and automation.

IMMS modelling tool for robust and stable drive systems in autonomous mobile robots

The methodology developed at IMMS comprises solutions for the modelling, simulation and evaluation of omnidirectional drive systems for mobile robotics and has been implemented in software. For this purpose, various drive concepts were first systematically analysed and evaluated in terms of their kinematic and dynamic properties, their technical feasibility and their potential for expanding the range of motion.

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Mathematical kinematic and dynamic models were developed for selected concepts and implemented in a flexible Python-based software environment. The resulting modelling tool enables the parameterisation of geometric and system parameters, as well as the calculation of state variables and acting forces under specified driving dynamics scenarios. This allows, amongst other things, vertical, drive and lateral forces to be determined, and driving dynamics effects such as roll stability, as well as slip and skid conditions, to be assessed.

In addition, methods for optimised path planning and control were developed. The path planning takes account of both static and dynamic obstacles and generates collision-free trajectories whilst adhering to dynamic driving constraints such as speed and acceleration limits. A model-predictive controller was implemented for trajectory tracking, enabling robust and stable control of the entire system. The associated algorithms were also integrated into a software solution based on the CasADi optimisation library.

Modelling tool validated with differential drive by MetraLabs

The methods and software modules developed were comprehensively validated through simulation and, in part, successfully tested experimentally on a demonstrator platform with differential drive provided by the project partner Metra-Labs. This demonstrated the fundamental consistency between the model and the real-world system.

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A further focus was on the development and investigation of omnidirectional drive concepts, which enable lateral and diagonal movements in particular. These expanded movement capabilities were described in the model and analysed and validated in simulations with regard to their effects on driving dynamics.

The results achieved in the project were scientifically documented and submitted to, and accepted for, the International Conference on Methods and Models in Automation and Robotics (MMAR) 2026. The models, algorithms and software components developed are available as a reusable foundation for future research and development work.

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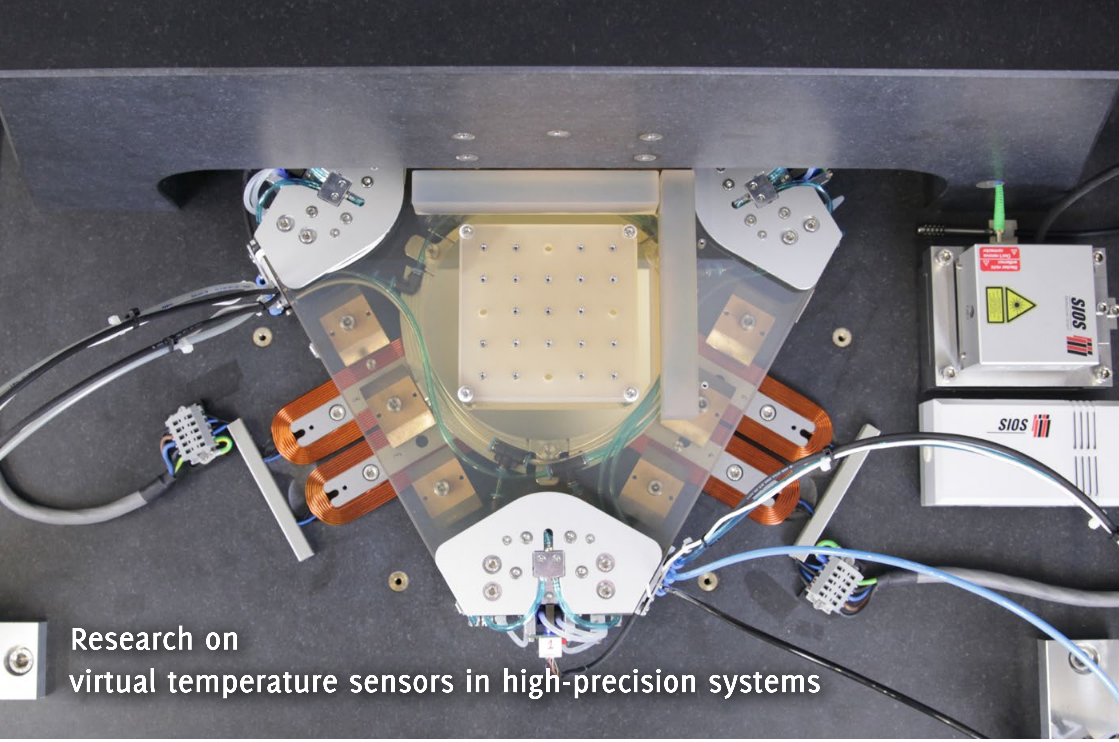

Research on virtual temperature sensors in high-precision systems

Using virtual sensing and AI, disturbances acting on complex mechatronic systems — such as high-precision drives — can be identified with spatial resolution and compensated for accordingly. Photograph: IMMS.

Motivation and overview

High-precision nanopositioning systems (NPS) are essential in modern manufacturing, metrology, and semiconductor applications, where positioning accuracy in the subnanometre range is required [1]. One of the greatest challenges with such systems is thermal disturbance, which leads to structural deformation and positioning errors [2]. Although temperature measurements are crucial for thermal compensation, sensor placement is often limited due to space constraints, functional requirements, and system complexity. As a result, it is not possible to directly measure the temperature at all relevant locations within the system.

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The VirtuSen project aims to address this limitation by developing AI-based virtual sensors that estimate temperature fields at inaccessible locations using a combination of sparse sensor measurements, physics-based models, and data-driven approaches. The central innovation lies in combining physical modelling with artificial intelligence, enabling accurate and physically consistent predictions even

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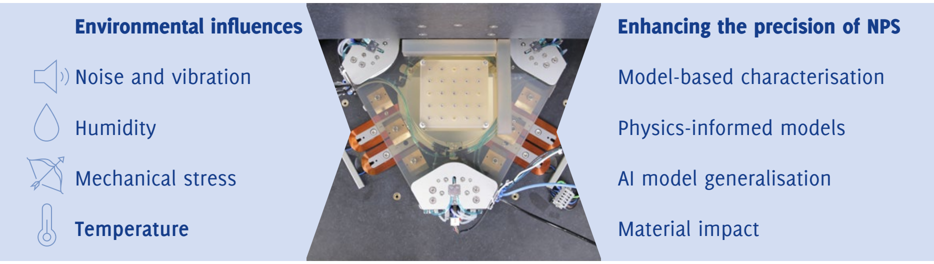


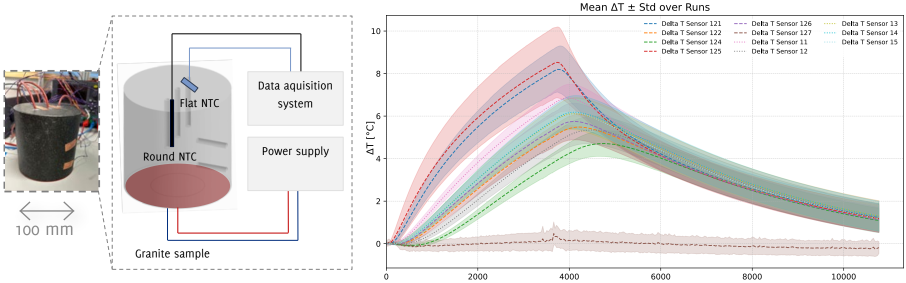
Figure 1: Factors influencing high-precision positioning systems and possible solutions. Graphic: IMMS.

with limited sensor data. The overall approach follows a stepwise strategy: starting with controlled experiments on material specimens, progressing to simplified nanopositioning systems and ultimately extending to real-world systems with limited sensor accessibility. This methodology ensures that the developed models are both accurate and transferable to practical situations.

Investigation and modelling of thermal behaviour

To establish a reliable basis for temperature prediction, both experimental studies and physical modelling are conducted. The experiments are performed on specimens of hard rock and mineral castings, which are commonly used in precision engineering applications. The specimens are specifically designed to allow for a detailed investigation of temperature gradients by embedding sensors at various depths and positions. The experimental results provide insights into heat propagation within the material, including differences between surface and internal temperatures as well as the influence of environmental conditions such as convection. At the same time, limitations regarding measurement uncertainty, repeatability, and sensitivity to boundary conditions are identified.

In parallel, transient 3D models are developed using numerical simulation tools to describe the thermal behaviour and replicate the actual experimental conditions. These models are used to calculate the spatial and temporal temperature distribution, enabling a systematic analysis of influencing factors such as heat input and boundary conditions. Although a general agreement between simulation and experiment is achieved, discrepancies remain due to uncertainties in material properties and boundary conditions. Reducing these discrepancies and ensuring transferability to more complex geometries are ongoing tasks.



(a) (b)

Figure 2: (a) Initial experimental setup using a granite cylinder (100 mm). (b) An example of the averaged temperature distribution in a granite cylinder sample. Source: IMMS.

Development of AI-based virtual sensors

Based on the experimental and simulated data, several AI-based approaches are investigated to assess the feasibility of virtual temperature measurement. Classical machine learning models, deep learning architectures, and physically informed neural networks (PINNs) are implemented and compared. The results show that temperature estimation based on limited sensor data is fundamentally feasible. Sequential models, in particular, demonstrate the ability to capture temporal behaviour, while physics-informed approaches provide a framework for incorporating physical constraints into the learning process. However, significant challenges remain. The models exhibit sensitivity to sensor configuration, limited robustness under changing operating conditions, and difficulties in accurately capturing local thermal effects or unknown heat sources. These observations suggest that further methodological development, together with the integration of improved data acquisition and modelling approaches, is required to achieve reliable performance.

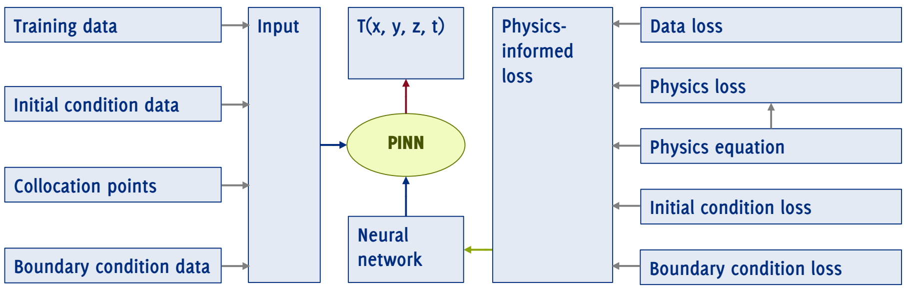


Figure 3: Schematic overview of the training framework of a PINN. Graphic: IMMS.

Generalisation and transfer of AI Methods

A key objective of the project is to apply the developed methods to real-world nanopositioning systems, where only a limited number of surface sensors are available and no direct reference measurements are possible at the desired locations. Initial investigations show that while the models perform well under controlled experimental conditions, their transfer to more complex systems remains a major challenge. In particular, structured prediction errors, uncertainties in the model outputs, and dependence on the training data limit the direct applicability of current approaches. Furthermore, the integration of physical models and AI methods at the system level has not yet been fully validated. To address these challenges, the next step involves applying the developed methods to a simplified nanopositioning system in which partial internal sensing is still possible. This intermediate step enables a systematic evaluation of model transferability and provides important insights for further development.

Outlook and potential applications

The work carried out so far represents a first step toward implementing virtual temperature measurement in high-precision systems. However, considerable effort is still required to improve the accuracy, robustness, and generalisability of the models. In the next phase, the focus will be on refining the experimental setups, improving the physical models, and further developing AI-based methods to better handle limited data and uncertainties. Following validation on simplified systems, the approach will be extended to a real-world nanopositioning system with limited sensor equipment.

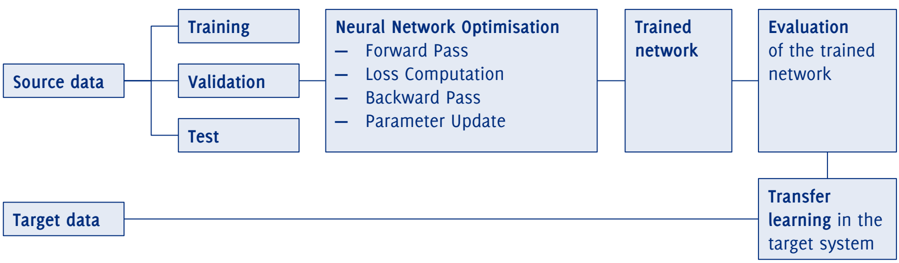


Figure 4: Training and transfer processes in neural networks. Graphic: IMMS.

The long-term goal is to combine simplified physical models with AI-based virtual sensors to predict the entire temperature field and identify unknown thermal disturbances within the system. The developed methodology offers significant application potential for a wide range of precision engineering systems, particularly those developed at IMMS where direct measurement of internal states is not possible. By combining physical understanding with artificial intelligence, the project contributes to the development of intelligent, self-monitoring systems that can maintain high performance under changing operating conditions. This would enable more effective thermal compensation strategies and contribute to maintaining high positioning accuracy. Beyond nanopositioning systems, the developed methods have potential applications in a wide range of fields in precision engineering, including machine tools, measurement systems, and other mechatronic systems where internal states cannot be measured directly.

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The research group ‘Application of AI-based virtual sensor technology to effectively increase the precision of positioning systems – VirtuSen’ was funded by the German Land of Thüringen.

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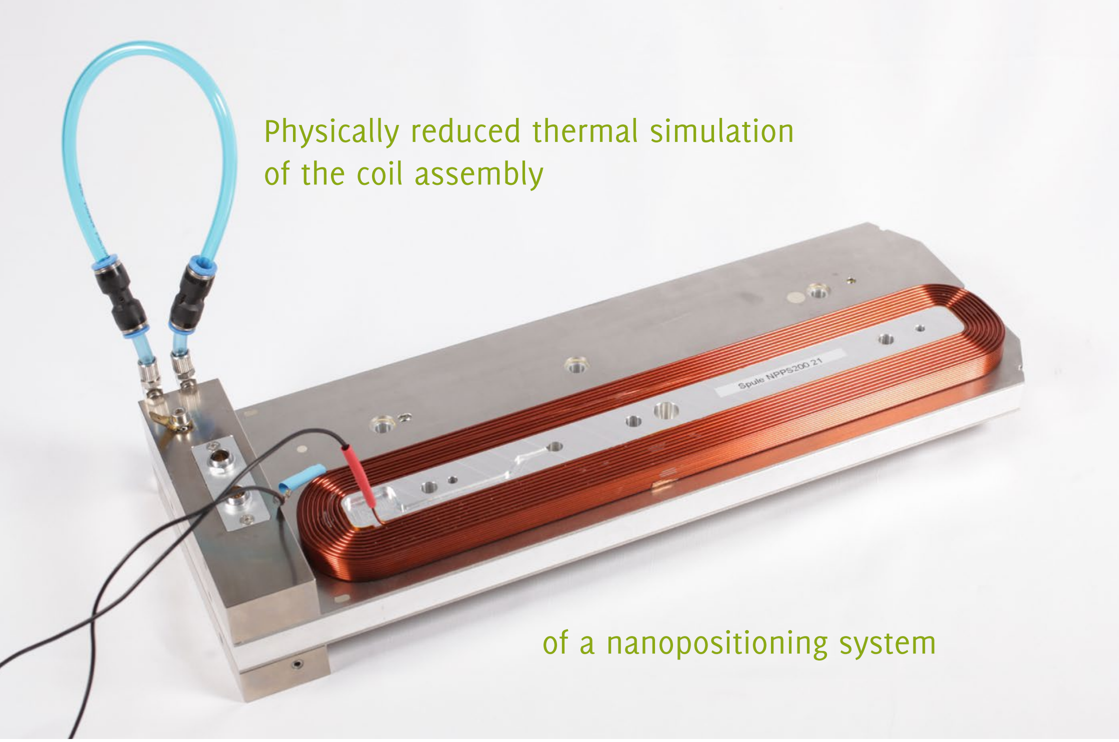
Physically reduced thermal simulation of the coil assembly of a nanopositioning system



Coil and coil assembly of a nanopositioning system, whose thermal behaviour has been simulated in physically reduced models. Prospectively, it is possible to improve the systems by predicting and compensating for disturbance influences. Photograph: IMMS.

Reduced modelling for efficient simulation of thermal effects

Nanopositioning systems (NPS) are employed across a range of industries – including nano and micro technology – to position and manipulate objects. As the trend moves toward smaller and more complex structures, the demands on the dynamics and positioning accuracy of nanopositioning systems continually increase. In these precision regimes even minor disturbances, such as thermally induced deformations, can negatively affect positioning accuracy. Therefore, it is essential to predict the performance of nanopositioning systems through modelling, so that emerging disturbances can be compensated for in the future. Because these models involve highly computationally and time intensive simulations, research is focused on whether high accuracy results can also be achieved with reduced models. The VirtuSen research group concentrates on predicting disturbances such as temperature changes caused by heat sources that generate stresses and deformations, thereby impairing accurate positioning.

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› Distributed measurement + test systems
› nm-precise 6D direct drives
› Contents
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In the VirtuSen research group, the IMMS team succeeded in reproducing the thermal behaviour of a coil assembly in a physically reduced model for numerical fluid dynamics (Computational Fluid Dynamics; CFD) within the ANSYS Fluent simulation software. By reducing the model, it becomes possible to efficiently examine a variety of operating points. Based on this, the cooling of the coils can be optimised, and the thermal influence of the coil assembly on the other components of the nanopositioning system can be investigated. In the future, deformations are also to be predicted and compensated for before they can negatively affect positioning.

Coil assemblies of a nanometre accurate high precision drive

The coil assembly is installed thrice in the planar drive of the positioning system **NPS6D200** rotated by 120° each (Figure 1(a): A, B, C). This nanometre accurate positioning system, developed at IMMS, was realised as part of various earlier research projects for a planar workspace of Ø 200 mm. The new feature of the NPS6D200 was the extension of an integrated planar direct drive with a vertical actuation of 25 mm travel. The combination of planar and vertical drive allows closed loop control in six degrees of freedom (6 D). The electric coils of the planar drive heat up due to Ohmic losses. The resulting temperature differences cause heating of surrounding structures through direct or indirect contact via various heat transfer mechanisms. Among other components, the system's granite base is exposed to these heat sources, ultimately leading to stresses and deformations.

Specialist article on the NPS6D200: www.imms.de

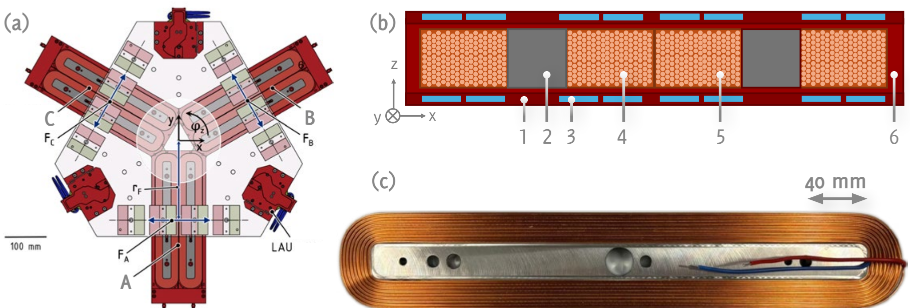

Figure 1:

(a) Schematic representation of the planar drive system;
(b) Schematic cross section of a coil assembly: 1) cooling element sandwiches, 2) coil cores, 3) cooling channels, 4/5) wound copper wire, 6) coil frames;
(c) Photograph of a coil with its core and electrical connections. Graphics/Photograph: IMMS.

The aim of the work carried out at IMMS was to predict the thermal behaviour of the coils and coil assemblies under various loads using a reduced simulation. This will enable optimisation of coil cooling, determination of their thermal influence on the entire positioning system, and, in the long term, improvement of the overall positioning accuracy of the nanopositioning system by compensating for the resulting deformations.

The coil assemblies, shown schematically in Figure 1(b), consist of two coils made from wound copper wire (4, 5) and aluminum coil cores (2), aluminum coil frames (6), and the so called cooling element sandwiches (1). These sandwiches enable temperature control of the coils via embedded cooling channels (3).

The thermal simulation of the entire coil assembly was divided into several subsystems: first, the coil itself was examined, and a geometric reduction of the coil model was performed. Next, the cooling element sandwiches were simulated separately, a process that is highly computationally intensive due to the coolant and finally, the entire coil assembly was simulated. All simulation results were validated with equivalent experiments.

Investigation and physically reduced simulation of the coils

The **investigation of the coils** was first carried out microscopically to determine their composition. As shown in Figure 2, the coil windings consist not only of copper wire (1) but also of various coatings (2), a filling material (epoxy) (6), a polyamide film (3) to isolate the windings from the coil core (5), and air gaps (4).

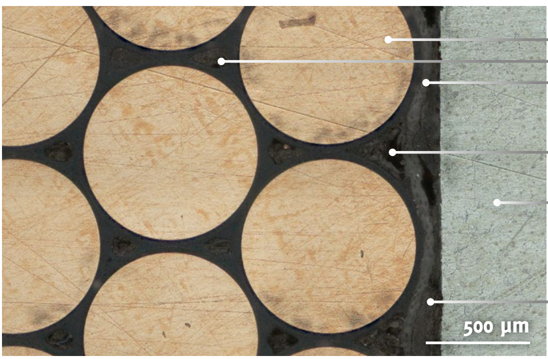

Figure 2:

Microscope image of a coil in cross section.

Photograph: IMMS.

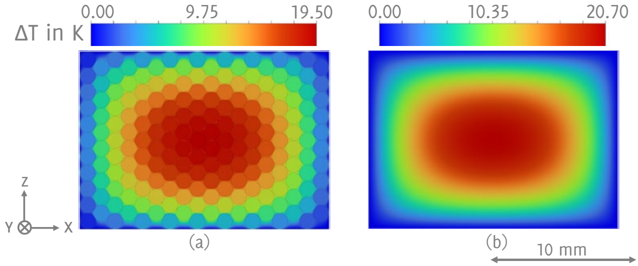

Figure 3:

Comparison of the resulting temperature gradients between a detailed simulation with all wires (a) and a reduced simulation with direction dependent thermal conductivity (b).

Graphic: IMMS.

Because simulating every geometric detail would require a very high computational effort, a geometrically **reduced model** was devised. First, all filler materials were combined into a single material with averaged properties. The remaining copper wires and the averaged filler material were examined in more detail to determine their thermal characteristics, with particular emphasis on the thermal conductivity of the proposed substitute material. Based on the coil cross section (Figure 1(b)) and the shape of the coils as seen in Figure 1(c), it was assumed that the thermal properties are direction dependent. To investigate this, a separate simulation was performed. It compared the resulting temperature gradient from a simulation with the detailed model (Figure 3(a), S1) to that from the simulation using the substitute material (Figure 3(b)). The comparison was carried out once with direction dependent thermal conductivity (S2) and once with direction independent thermal conductivity (S3).

Table 1 shows the percentage deviation of the resulting heat flux densities from the simulations at the corresponding outer walls. It demonstrates that the directional dependence of thermal conductivity must not be neglected.

	Deviation S2 / S1 in %	Deviation S3 / S1 in %
Left wall	−3,40	−14,80
Right wall	−2,82	−14,29
Top wall	5,57	14,88
Bottom wall	5,56	14,88

Table 1: Comparison of the resulting heat flux densities of simulations S1, S2, and S3 at the walls. Source: IMMS.

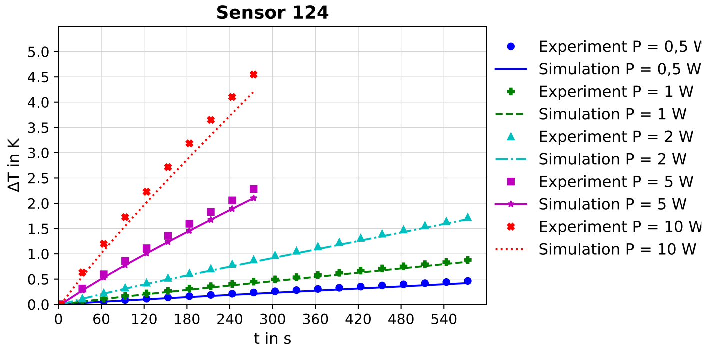

Figure 4: Diagram of the resulting temperature difference between simulation and experiment for a representative sensor with average deviation.

Graphic: IMMS.

In a subsequent step, an entire coil was simulated transiently with various applied power levels and experimentally validated. The difference between the measured and simulated resulting temperature differences, referenced to the respective starting temperature, was determined separately for each sensor used in the experiment. As illustrated in Figure 4 for a representative sensor on the coil winding, the results show a small deviation from one another. The chosen sensor exhibits an average deviation from the other sensors. This suggests that the reduced coil model is suitable for use in simulations of the entire coil assembly.

Simulation of the cooling element sandwiches and the entire coil assembly

The **simulation of the cooling element sandwiches** focuses on accurately representing the coolant. To capture the flat, long geometry of the cooling channel, the mesh shown in Figure 5 was chosen, with one computational point per mesh volume. Care was taken to select the boundary layers correctly, as they are essential for calculating the heat transfer between fluid and solid. The resulting simulation of the cooling element sandwiches — validated against experimental data — was finally incorporated into the simulation of the entire coil assembly.

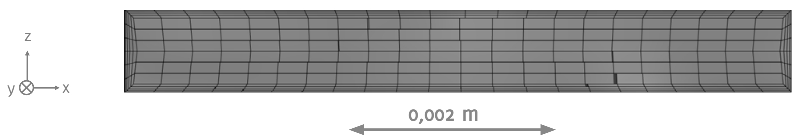

Figure 5: Mesh representation of the cooling channel. Graphic: IMMS.

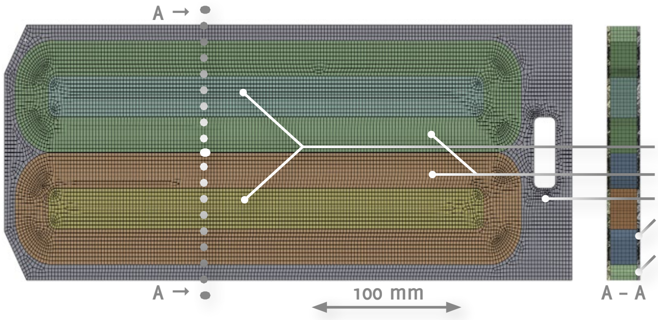

Figure 6:

Mesh representation of the coil assembly:

1) Coil core
2) Coil winding
3) Coil frame
4) Cooling-element sandwiches
5) Cooling channels.

Grafik: IMMS.

The **simulation of the entire coil assembly** was first carried out by selecting the thermal contact resistances between the solid bodies, as these have a significant influence on heat transfer between the individual components. The simulation was then performed for various power levels applied to the coils to cover a wide range of possible operating points. Figure 6 shows the chosen mesh of the individual parts of the coil assembly, with most of the mesh cells located inside the cooling channels of the cooling body sandwiches. This, as already explained, is due to the required high resolution in the fluid domain.

Figure 7 shows the resulting temperature distribution from the coil assembly simulation with an electrical input power of 10 W. The temperature of the cooling channel rises from the inlet (1) to the outlet (2), because the heat generated in the coils is absorbed by the coolant and transported out of the system. It is also evident that there is a temperature hotspot over one of the coils, which leads to a higher heat input into surrounding geometries.

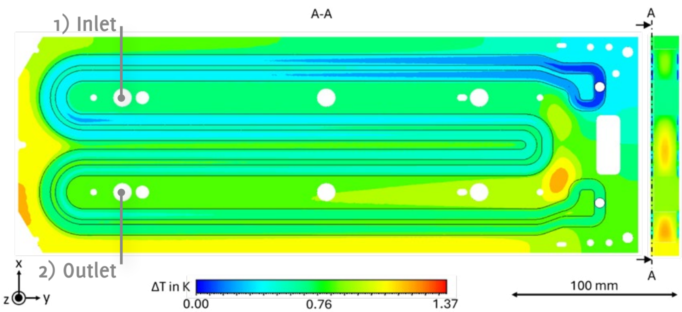

Figure 7:

Representation of the resulting temperature gradient from the coil assembly simulation with an electrical power of 10 W and a coolant inlet velocity of 0.202 m/s.

Graphic: IMMS.

The comparison between the simulation results and the experimental data shows a high degree of concordance. This indicates that the simulation accurately represents the system, and that the reduced geometry of the coils allows for faster computation of the results than a fully detailed geometric simulation, while still maintaining high accuracy.

Outlook

These results serve as the starting point for investigating the thermal influence of the coils and coil assemblies as one of the primary heat sources within the overall system on the surrounding or adjacent geometries. The simulation can predict which temperature gradients arise at different power levels and how they are distributed across the coil assemblies. For subsequent components — such as the granite base of the entire positioning system — the proximity to the coils as a heat source generates a temperature gradient. Because most materials, including granite, expand with increasing temperature, the coils introduce unwanted deformations into the overall system. Based on these findings, the VirtuSen research group studies the thermo mechanical response of the granite base and other adjacent systems and ultimately aims to efficiently thermomechanically simulate the entire nanopositioning system using a reduced model.

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The research group 'Application of AI-based virtual sensor technology to effectively increase the precision of positioning systems – VirtuSen' was funded by the German Land of Thüringen.

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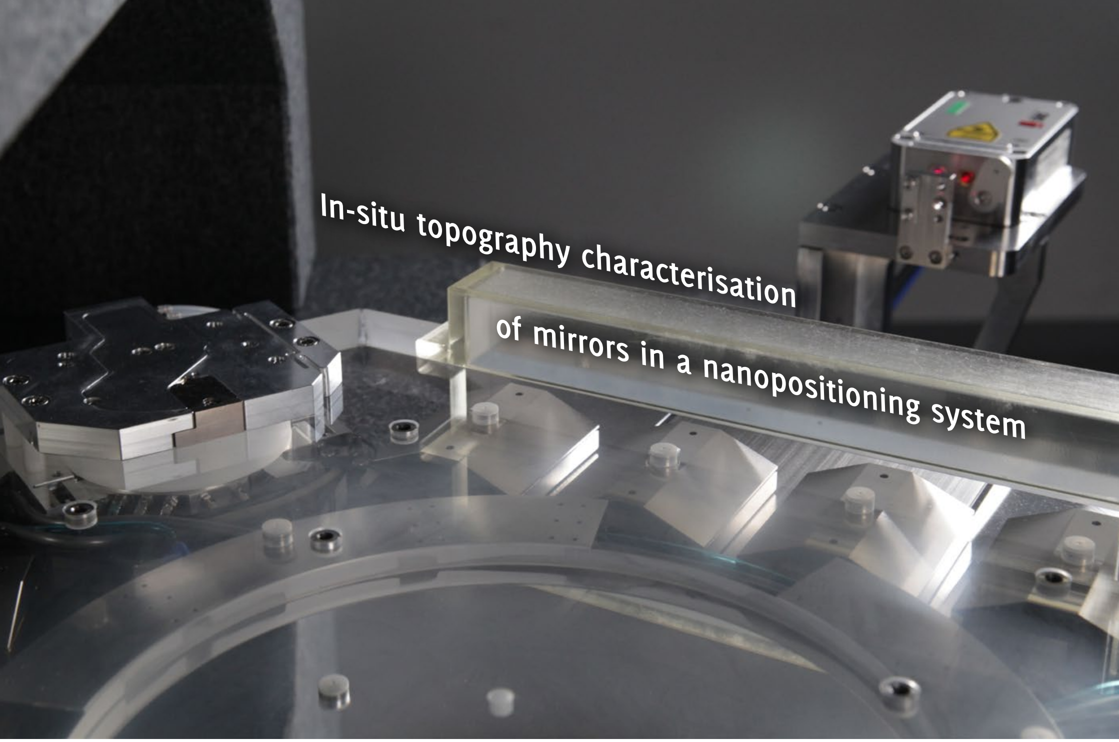

In-situ topography characterisation of mirrors in a nanopositioning system

IMMS has developed an approach that allows the reference mirrors to be characterised directly within the overall structure of a positioning system. Deviations from the ideal state of the mirrors can thus significantly improve positioning accuracy through corrective calculations. Photograph: IMMS.

Motivation and overview: the hidden impact of mirror imperfections on nanopositioning accuracy

www.imms.de/nmdrives

High-precision nanopositioning systems are essential in advanced manufacturing, nanometrology, and scientific instrumentation. These systems enable controlled motion with sub-nanometre resolution over travel ranges of hundreds of millimetres – comparable to locating a single needle within a city the size of Ilmenau.

Specialist article on the NPS6D200: www.imms.de

IMMS has developed the NPS6D200, a long-range volumetric nanopositioning system designed for six-degree-of-freedom (6-DOF) control – three translational and three rotational degrees of freedom – using interferometric feedback for position sensing. At the heart of its metrology are four planar reference mirrors, which serve as fixed reference surfaces for internal sensors, including laser interferometers and an autocollimator.

The system's control architecture assumes initially that these mirrors are geometrically ideal – perfectly flat and precisely aligned. However, in practice, deviations from this assumption can significantly degrade performance. Even small errors in mirror geometry can compromise the system's ability to accurately determine position and orientation. For example, if the mirrors are not perfectly flat, the system may "lose" the reference point – just as it would be impossible to find the location in a city if the map itself is distorted.

These deviations propagate through the feedback loops and contribute to systematic errors in coordinate reconstruction, including cosine errors and parasitic motions. Without correction, such errors reduce positioning accuracy and measurement reliability.

IMMS has developed an approach that allows the actual surface topography of the reference mirrors to be characterised directly within the overall assembly of a positioning system. The measured mirror geometry, including any deformations, is corrected internally via a coordinate reconstruction of the system. This allows the positioning accuracy to be significantly improved without the need to modify the hardware or control architecture, whilst taking real-world deviations into account. This is comparable to providing the correct glasses to someone with poor eyesight: just as the wrong lens distorts the world, assuming a perfectly flat mirror leads the machine to perceive the position incorrectly.

Introduction: the challenge of measuring what's already in use

The NPS6D200 (figure 1) is a long-range nanopositioning system designed for six-degree-of-freedom (6-DOF) control – meaning it can move and rotate in three directions (X, Y, Z) and three rotational axes (yaw, pitch, roll). It achieves nanometre-level precision over a horizontal range of 200 mm and a vertical range of 25 mm.

To track its position, the system uses four planar mirrors:

- Mirror U: Controls yaw rotation (φ_Z),
- Mirrors V and W: Control X and Y translation,
- Mirror Z: Controls Z translation and X/Y rotation (φ_X und φ_Y) – pitch and roll.

Internal sensors – laser interferometers and an autocollimator – rely on the four reference mirrors to measure the system's position and orientation. However, because these mirrors are not perfectly flat or perfectly aligned in practice, real-world effects degrade their performance. Gravity pulls downward on the mirrors, causing them to sag slightly – similar to how a wire sags between two supports under its own weight.

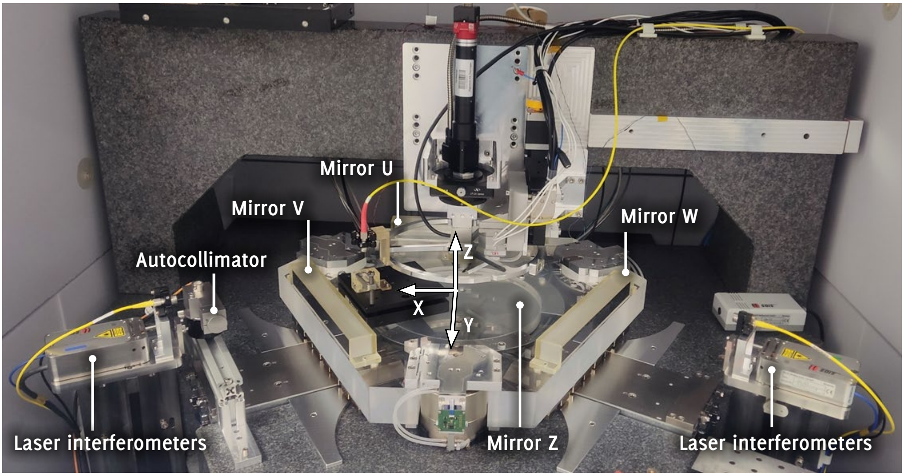

Figure 1: NPS6D200 equipped with an external autocollimator. Photograph: IMMS.

Clamps that secure the mirrors in place can introduce uneven pressure, leading to localised warping or bending. Even during manufacturing, no mirror is perfectly flat – deviations in surface form are inevitable. Over time, temperature changes and mechanical vibrations can further shift the mirrors' positions or stresses, introducing small but cumulative changes. Together, these factors mean that the mirrors deviate from the ideal geometry, leading to systematic errors in motion and positioning that can compromise measurement accuracy.

These effects propagate through the system's feedback loops, distorting the machine's internal map. The result is that the machine "believes" it has reached the correct position, but in reality, it is offset – leading to systematic errors in measurement. Traditional ways to measure mirror shape – like using a high-resolution profilometer – require removing the mirrors from the machine. But that's like taking a car's suspension apart to measure its alignment: once you reassemble it, the alignment is different.

So, an alternative is proposed: a method that measures the mirrors while they are still in place, under real working conditions.

Experiment details: how we measured the mirrors without touching them

The experiment was conducted on the NPS6D200 nanopositioning system using external tools without modifications to the machine.

As equipment three compact autocollimators from our partner SIOS are being used: small, portable devices that measure angular deviations with high sensitivity (±50 arcsec range). The autocollimators were mounted outside the machine and carefully aligned to the centre of each mirror. The system was operated in its normal configuration – no disassembly, no changes to the control software.

Additional equipment:

- One high-precision reference autocollimator ELCOMAT® HR manufactured by Möller Wedel was used to verify the accuracy of the other autocollimators.
- A 12-faced optical polygon: A calibrated precision angular standard used as reference surface for autocollimators verification.

To ensure accuracy, the autocollimators were verified in a different experiment against the reference autocollimator in a range of ±50 arcsec using the optical polygon.

Procedure: From Angles to 3D Maps

The procedure for mirror topography reconstruction was divided into five steps:

1) Identification of controlled degrees of freedom:

The system uses mirror U to control yaw (φ_Z) and mirror Z to control roll (φ_X) and pitch (φ_Y). Mirrors V and W are not used in these control loops, making them suitable for external measurement.

2) Coordinate system definition:

A local coordinate system was defined for each mirror:
- Origin: Centre of the mirror,
- Horizontal axis: Points left when viewing the reflective face,
- Vertical axis: Opposite to the machine's vertical direction (downward),
- Normal axis: Positive height corresponds to outward movement from the mirror surface.

3) Direct displacement measurement (single-DOF detection):

For yaw characterisation, measurements were taken on mirrors V and W, see figure 2, as mirror U is used in the yaw control loop and obtained by equation 1. By measuring at multiple heights and accounting for initial angular offsets, the full topography of mirror U was reconstructed.

For roll characterisation, measurements were taken on mirrors U, V, and W, as mirror Z is used in roll control. The autocollimators were aligned to the mirror centre, and perpendicular movements were performed to maintain beam alignment.

4) Relative displacement measurement:

After direct measurements, relative displacements were determined. For example, the yaw topography of mirror V was obtained by subtracting the scaled-up measurement from mirror U from the measured signal. Similarly, roll topographies of mirror W were derived using subtraction of mirror U topography:

$$\theta_U = -\theta_{VV} = -\theta_{WW} \tag{Equation 1}$$

Where θ_U is the yaw topography of the mirror U, θ_{VV} ais the angular topography obtained measuring the mirror V with a movement in V perpendicular direction and θ_{WW} is the angular topography obtained measuring the mirror W with a movement in W perpendicular direction.

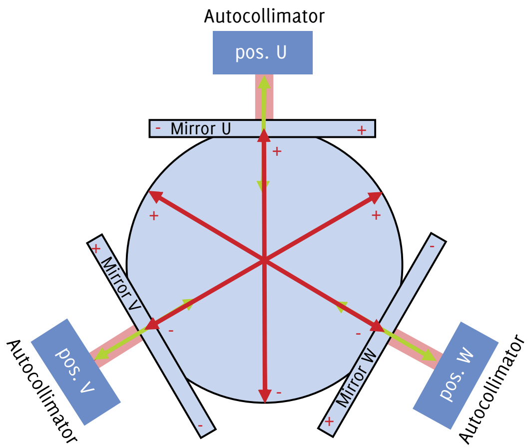

Figure 2: Position of the autocollimators in respect of the mirrors and movements for topography detection.

Graphic: IMMS.

5) Secondary relative displacement and mirror Z reconstruction

A star-shaped motion path was used to measure multiple points on mirror Z. Since pitch rotation is not directly measurable by the autocollimators, two measurement positions were used to solve a system of two equations with two unknowns described by equation 2. The solution was obtained using a least-squares method. The final topography was reconstructed using geometric integration.

$$\varphi_{UStar}(x,y) = \varphi_U(x) + \varphi_Z \cdot \sin(\alpha) + \varphi_{ZP} \cdot \cos(\alpha)$$
$$\varphi_{VStar}(x,y) = \varphi_V\left(-x \cdot \sin\left(\pi/6\right) + y \cdot \cos\left(\pi/6\right)\right) + \varphi_Z \cdot \sin\left(\alpha - 2\pi/3\right) + \varphi_{ZP} \cdot \cos\left(\alpha - 2\pi/3\right)$$
$$\varphi_{WStar}(x,y) = \varphi_W\left(-x \cdot \sin\left(\pi/6\right) - y \cdot \cos\left(\pi/6\right)\right) + \varphi_Z \cdot \sin\left(\alpha + 2\pi/3\right) + \varphi_{ZP} \cdot \cos\left(\alpha + 2\pi/3\right)$$

Equation 2

The terms of the equation are described in table 1.

Symbol	Description
φ_{UStar}	measured topography of the mirror Z measured from mirror U
φ_{VStar}	measured topography of the mirror Z measured from mirror V
φ_{WStar}	measured topography of the mirror Z measured from mirror W
φ_U	roll topography of the mirror U
φ_V	roll topography of the mirror V
φ_W	roll topography of the mirror W
φ_Z	roll topography of the mirror Z (direction of the movement)
φ_{ZP}	topography that the autocollimator doesn't detect when it measure (pitch rotation)

Table 1: Terms of equation 2.

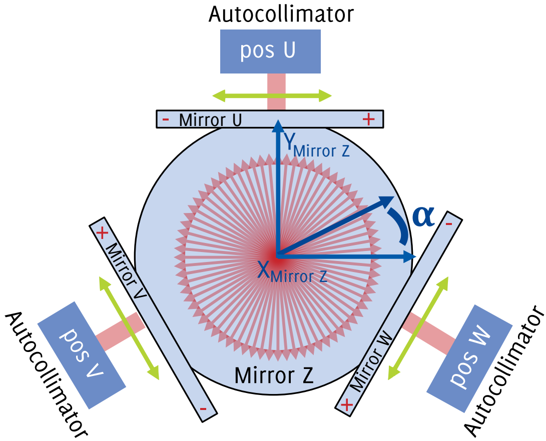

Figure 3:

Position of the autocollimators in respect of the mirrors and movements for topography detection.

Graphic: IMMS.

All measurements were performed at a speed of 5 mm/s. Thermal drift was compensated by defining a common origin at the centre of the measurement path.

Results: what the mirrors really look like

The reconstructed surface topographies of the four reference mirrors are shown in Figure 4. The results reveal deformation patterns that reflect the interplay of mechanical forces and mounting conditions.

Mirror Z exhibits the largest deviations, with values reaching approximately −1300 nm in a localised region near the lower edge. This highly localised deformation does not follow the expected pattern of uniform gravity-induced sag over three support points of the slider, where deflection would typically be symmetric and distributed across the surface. Instead, the deformation is confined to a specific area. This feature is more likely attributable to manufacturing imprecision such as non-uniform tool path during polishing.

Mirror U displays relatively small and smooth variations, with deviations ranging from about −300 nm to +300 nm across the surface. Slight increases in deviation near the edges suggest minor effects from clamping or mounting misalignment.

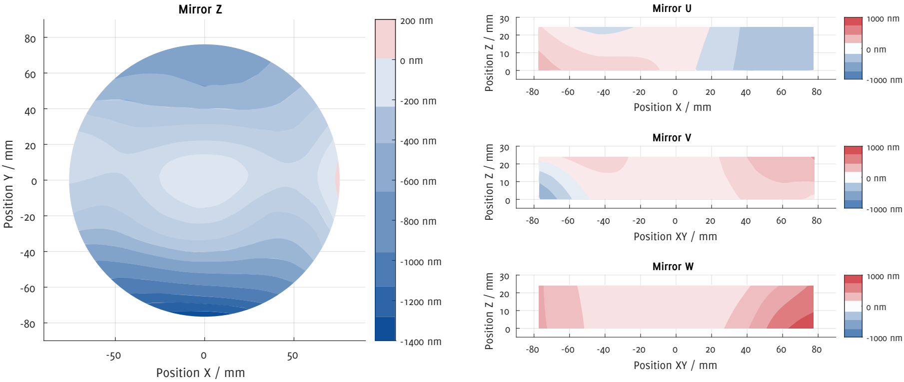

Figure 4: Topography of all machine mirrors obtained by the method. Graphic: IMMS.

Mirror V shows a symmetric deformation, with the central region remaining close to zero and deviations increasing toward the edges, reaching −500 nm. This behaviour is consistent with bending caused by clamping forces.

Mirror W, in contrast, shows deviations up to +800 nm, with a concave shape near the clamping regions. The deformation pattern differs from that of Mirror V, indicating asymmetry in how mechanical loads are transferred through the structure or in the mounting configuration.

Together, these findings indicate that mechanical constraints, mounting-induced stresses, and manufacturing imperfections are significant contributors to systematic errors in the nanopositioning system. The reconstructed topographies reflect a combination of intrinsic surface form, residual misalignment, and localised deformations arising from both mechanical loading and fabrication-related effects. While gravitational deformation is present in regions consistent with support geometry, such as gradual bending near the edges, the depression in Mirror Z is localised and asymmetric, suggesting it stems primarily from manufacturing imprecision, such as non-uniform tool paths or residual stress, rather than uniform mechanical loading. This confirms that both structural design and production quality play critical roles in determining the system’s metrological performance.

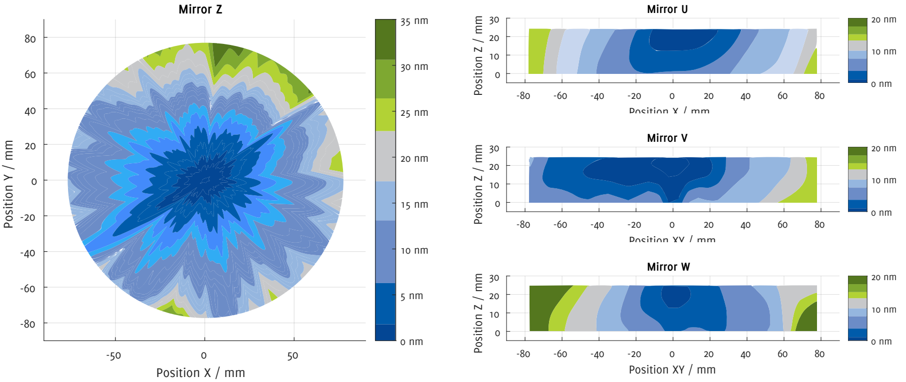

Figure 5: Standard deviation of the topography of all machine mirrors obtained by the method. Graphic: IMMS.

Reproducibility: how reliable are the measurements?

The standard deviation of the reconstructed topographies is presented in Figure 5. This map provides insight into measurement repeatability and the propagation of uncertainty through the hierarchical reconstruction process.

Mirror Z exhibits the highest variability, with standard deviations reaching up to 31 nm, particularly near the edges. This increased uncertainty arises because the mirror's topography is reconstructed last, relying on multiple relative measurements and a least-squares solution, which amplifies small errors from earlier steps.

In contrast, **Mirror U** shows the lowest uncertainty, with standard deviations remaining below 12 nm across most of the surface, and slightly higher values only at the edges. As the first mirror measured, its reconstruction is independent of prior results, making it the most stable reference.

Mirror V displays standard deviations similar to those of Mirror U, with slightly elevated values in the positive XY regions, likely due to edge effects and measurement sensitivity.

Mirror W shows intermediate variability, with standard deviations reaching 17 nm, primarily at the edges — consistent with the propagation of uncertainty from the earlier reconstruction of Mirror U.

The overall trend of increasing standard deviation from Mirror U to V and W, and finally to Mirror Z, reflects the hierarchical nature of the method. Additional sources of variability include small differences in the machine's initial alignment after start-up – on the order of 0.1 mm – coupling between rotational degrees of freedom in the autocollimator, and environmental influences such as air currents during motion.

Conclusion: a practical path to higher precision

This work demonstrates that by using three external autocollimators, it is possible to map the surface topography of all four reference mirrors in a nanopositioning system under real operating conditions. The method captures real-world effects such as gravitational sag, clamping-induced stress, and mounting-related deformations – factors that can be overlooked when assuming ideal mirror geometry. However, the observed deformation in Mirror Z – where a localised depression of up to −1300 nm occurs near the lower edge – does not follow the expected symmetric pattern of gravity-induced sag over three support points. Instead, its asymmetric and localised deviation suggests it is more likely attributable to manufacturing imprecision, such as non-uniform tool paths during manufacturing, rather than mechanical loading alone.

By incorporating the measured mirror geometry – including both global and localised deformations – into the system's internal coordinate reconstruction, positioning accuracy can be significantly improved without requiring any modifications to the machine's hardware or control architecture.

The approach is fully in-situ: the mirrors are characterised while remaining in their operational mounting and loading conditions, eliminating the risk of altering their mechanical state through disassembly. All measurements are traceable through verification against a reference autocollimator and an optical polygon standard. The procedure enables accurate, in-situ characterisation of reference mirror geometry without system modifications, making it well-suited for integration into routine calibration and monitoring workflows in high-precision systems.

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Funded by

DFG Deutsche Forschungsgemeinschaft

The Research Training Group 2182 on Tip- and laser-based 3D-Nanofabrication in extended macroscopic working areas (NanoFab) was funded by the German Research Foundation (DFG) under the funding code DFG GRK 2182.

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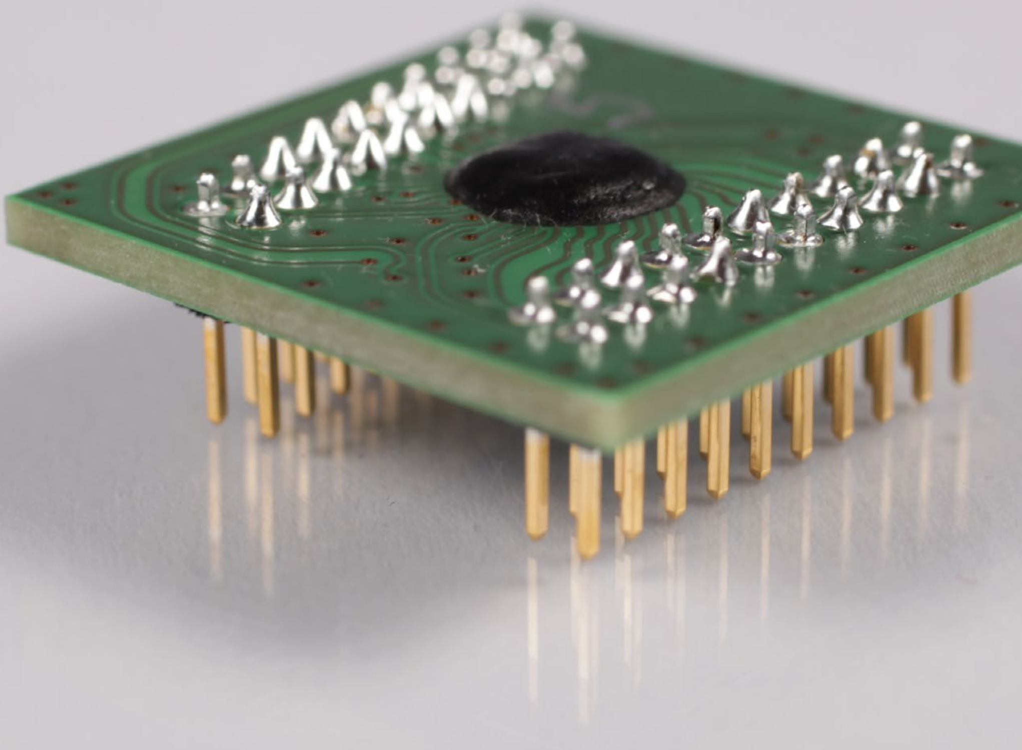
PROOF THROUGH FACTS AND FIGURES

Chip-on-board assembly for the D1038A test chip developed at HoLoDEC. It contains, as a separate unit, the analog part of a larger RFID sensor chip as well as an I^2C interface, and is used for detailed laboratory characterisation of the analog section. Details of the newly developed chip design methodology can be found in the technical article ‘Generator-based design for ultra-low-power mixed-signal circuits’ in this report. Photo: IMMS.



With funding from the:

Federal Ministry of Research, Technology and Space

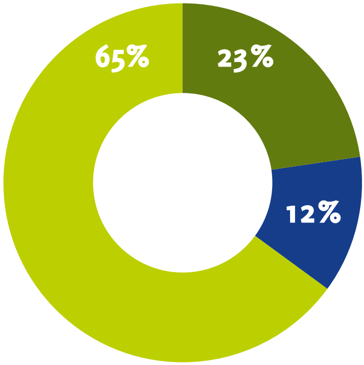
The **HoLoDEC** project on which this report is based was funded by the German Federal Ministry of Research, Technology and Space (BMFTR) under the reference **16ME0703**. The author is responsible for the content of this publication.

Facts and figures in 2025

At the end of the 2025 financial year, 97 **employees** of various nationalities and specialisations were working at IMMS.[1]

Of these, 63 scientists and 22 students were employed in research and development. This corresponds to around 87 % of all employees. In addition, 4 of the 12 employees assigned to administration were directly employed to support research.

Staff structure



Scientists | Students | Administration / apprentices

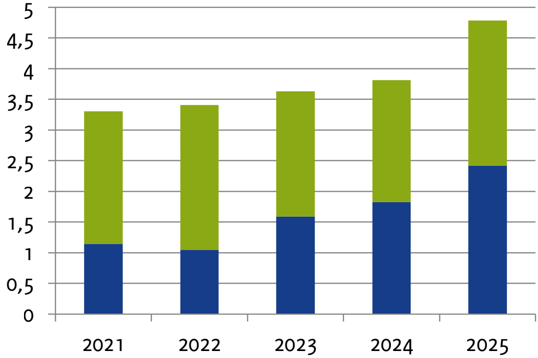
As part of training in practice-oriented research, a total of 37 students were supervised at IMMS in the financial year, including 4 Bachelor's theses and 10 Master's theses. 6 employees were enrolled as doctoral students at a university and 1 of them successfully completed his doctorate in 2025.

In 2025, we were able to launch a newly structured internal research group funded by the German Land of Thüringen. This gives three graduates the opportunity to conduct research into key research topics and pursue their PhDs.

Third-party funding earnings increased further in the 2025 financial year, rising by around 25 per cent compared with the previous year's figure. Both earnings from industrial contract research (industrial projects) and earnings from publicly funded research projects (funded projects) reached their highest levels. A total of 59 industrial projects were carried out during the financial year. In the 2025 financial year, 11 publicly funded research projects (funded projects) were launched, bringing the total number of funded and industrial projects in progress to 83.

www.imms.de/funding

1 *The employee figures as of 31 December 2025 are shown without full-time equivalents. A comparison with reports from further periods in the past is therefore only possible to a limited extent.*



Project earnings
in million €

Funded projects

Industrial projects

The Institute's **funding** (revenue) for the 2025 financial year continued to consist of three main sources: publicly funded research projects (funded projects), industrial contract research (industrial projects) and institutional funding from Thüringen. Despite a significant reduction in the grant in 2025, institutional support from Thüringen remains the indispensable foundation for the research activities of IMMS. However, the importance of industrial contract research for the Institute's growth continues to increase.

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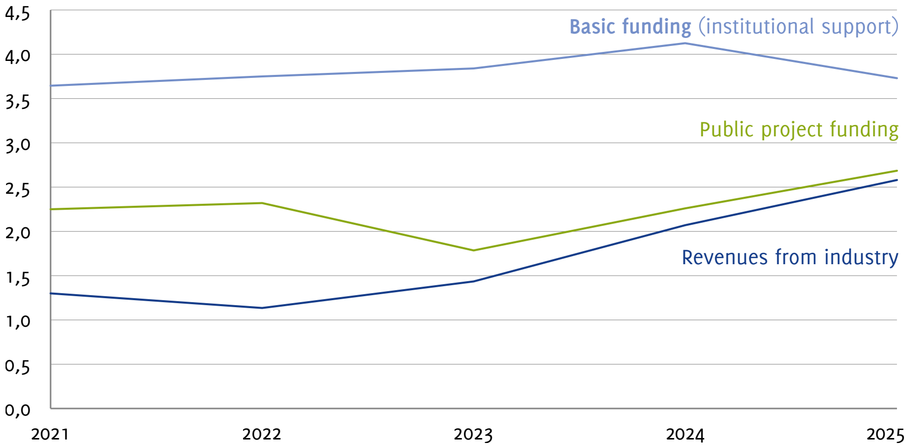
Pillars of financial support in million €



Organisation as of 31 December 2025

Scientific Advisory Board

Supervisory Board (Chair: TMWLLR[1])

Proprietor German Land of Thüringen

Management Board

Scientific Managing Director *(provisional)*
Martin Eberhardt, Dipl.-Kfm.

Financial Managing Director
Martin Eberhardt, Dipl.-Kfm.

Administration Mario Görlach, Business economist (VWA)

Research Areas

Corporate Communications Beate Hövelmans, Dipl.-Des. Dipl.-Hdl.

Microelectronics Eric Schäfer, M.Sc.

Mechatronics Ludwig Herzog, Dr.-Ing.

System Design Tino Hutschenreuther, Dr.-Ing.

Industrial Electronics and Measurement Technology Michael Meister, Dipl.-Ing.

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Supervisory Board

- **Chairman:** Dr. [1]Sebastian Stark, Head of division at Ministry of Economic Affairs, Agriculture and Rural Areas Thüringen (TMWLLR), Germany, Member of the Supervisory Board of BATT mbH
- **Deputy Chairwoman:** [1]Dr. Mandy Kandler, Deputy head of division at Ministry of Education, Science and Culture Thüringen (TMBWK), Germany
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- Andreas Rohwer, Head of division at Ministry of Finance Thüringen, Germany
- Univ. Prof. Dr.-Ing. habil. Kai-Uwe Sattler, President of Technische Universität Ilmenau; Member of the Administrative Board of TÜV Thüringen e.V., Germany
- Prof. Dr. rer. nat. Ingolf Voigt, Deputy Managing Director and Site Manager, Fraunhofer Institute for Ceramic Technologies and Systems IKTS, Hermsdorf, Germany, Member of the Board of TRIDELTA CAMPUS HERMSDORF e.V
- Jessica Völlger, CEO Melexis GmbH

- **Chairman**: Univ.-Prof. Dr.-Ing. habil. Martin Hoffmann, Ruhr University Bochum, Chair of Microsystems Technology, Faculty of Electrical Engineering and Information Technology *(until 31 August 2025)*
- **Deputy Chairman**: Prof. Dr. mont. Mario Kupnik, Technische Universität Darmstadt, Department of Electrical Engineering and Information Technology, Measurement and Sensor Technology Group (MuSt) *(until 31 August 2025)*
- Prof. Dr.-Ing. Holger Blume, Leibniz Universität Hannover, professor for "Architectures and Systems" and managing director of the Institute for Microelectronic Systems (IMS) *(since 1 September 2025)*
- Jörg Doblaski, Chief Technology Officer, X-FAB Semiconductor Foundries GmbH
- Dr. Alfred Hansel, CEO oncgnostics GmbH *(until 31 August 2025)*
- Prof. Dr. Doris Heinrich, Director of the Institute, Institut für Bioprozess- und Analysenmesstechnik e.V.
- Prof. Dr. Peter Holstein, Transfer entrepreneur, Steinbeis Transfer Centre Technical Acoustics and Applied Numerical Analysis
- Dr. Peter Miethe, CEO Posanova GmbH *(until 31 August 2025)*
- Univ.-Prof. Dr. Jens Müller, Technische Universität Ilmenau, Vice President for International Affairs and Transfer and Chair of the Electronics Technology Group, Faculty of Electrical Engineering and Information Technology
- Prof. Dr.-Ing. Wolfgang Nebel, Chairman of the Management Board of eda-centrum e.V. *(until 31 August 2025)*
- Dr. Jörg Petschulat, Head of Global R&D, Carl Zeiss SMT GmbH, ZEISS Semiconductor Mask Solutions
- Prof. Dr.-Ing. Ulf Schlichtmann, Technical University of Munich, Faculty of Electrical Engineering and Information Technology, Chair of Design Automation *(until 31 August 2025)*
- Prof. Dr.-Ing. Johannes Trabert, Ernst-Abbe-Hochschule Jena, University of Applied Sciences, Department of Electrical Engineering and Information Technology, Communications Systems and Transmission Technology
- Prof. Dr.-Ing. Norbert Wehn, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, Chair of the Microelectronic Systems Design (EMS) division *(since 1 September 2025)*

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Lectures, lecture series

Prof. Dr. Ralf Sommer, Ilmenau TU, Department Electronic Circuits and Systems:

- Basics of analog circuit technology, lecture and tutorial,
- Computer-aided circuit simulation and its algorithms (EDA), lecture and tutorial

Prof. Dr. Hannes Töpfer, Ilmenau TU, Department of Advanced Electromagnetics:

- Theoretical electrical engineering I and II, lecture
- Superconductivity and quantum information processing circuits, lecture
- Electromagnetic field, lecture
- Technical electrodynamics, lecture
- Project seminar TET

Dr.-Ing. Georg Gläser, Ilmenau TU, Department Electronic Circuits and Systems:

Design of digital and mixed-signal systems, lecture

Events

Conferences / events with contributions by IMMS

www.imms.de/events

11/03/2025 – AI Day for SMEs – BVMW e.V. Thüringen and ITnet Thüringen e.V. as part of the Thüringen Exhibition, *talk, exhibition booth*, Erfurt

02/04/2025 – Entrepreneurs' Morning – SaaleWirtschaft e.V., *talk, exhibition booth*, Rudolstadt

03/04/2025 – BTT Entrepreneurs' Evening – BTT Treuhand Steuerberatungsgesellschaft mbH, *talk*, Ilmenau

09/04/2025 – WID 2025 – World Interferometry Day, *poster, exhibition booth*, Ilmenau

12/05/2025 – edaWorkshop25 – Germany's leading event on electronics, design and applications (EDA), *talk*, Dresden

04/06/2025 – 2nd Specialist Conference by SaaleWirtschaft e.V. – Artificial Intelligence, Sustainability, Cyber Security and Legal Compliance, *talk*, Saalfeld

18/06/2025 – Canitz Eco-Field Days – A meeting place for the agriculture of tomorrow, *poster, demonstrators*, Canitz

18/06/2025 – Bernburg Innovation Days – Knowledge transfer and innovation for the agriculture of tomorrow, *talk*, Bernburg

25/06/2025 – **Thuringian Cherry Day 2025** – Thuringian State Office for Agriculture and Rural Affairs, Horticulture Training and Research Centre (LVG), *talk, demonstrator,* Erfurt
07/07/2025 – **SMACD 2025** – International Conference on Synthesis, Modeling, Analysis and Simulation Methods, and Applications to Circuit Design, *talk*, Istanbul
08/07/2025 – **MIMAR 2025** – International Conference on Modelling in Industrial Maintenance and Reliability, *talk*, Lorraine, Frankreich
16/07/2025 – **AI4PlantPhysio** – Workshop on plants and sensor technology as part of the AI4PlantPhysio project at the University of Konstanz, *talk*, Konstanz
20/08/2025 – **2nd Thuringian Hazelnut Day** – Thuringian State Office for Agriculture and Rural Affairs, Horticulture Training and Research Centre (LVG), *talk*, Erfurt
25/08/2025 – **ISSOM 2025** – International Summer School on Microelectronics, *lecture, exhibition booth*, Hannover
24/09/2025 – **W3+ FAIR JENA 2025** – Related conference „en-tech.talks“, *talk*, Jena
21/10/2025 – **elmug4future 2025** – Measurement Technology for Life Sciences: Markets, Requirements and Solutions, *talk, exhibition booth,* Jena
22/10/2025 – **Central German Digital Day 2025** – Fruit growing and viticulture, *workshop moderation,* Meißen
28/10/2025 – **Expert Day on Precision Measurement Technology** – talks, live demonstrations, expert sessions, guided tours at SIOS Meßtechnik GmbH, *talk*, Ilmenau
28/10/2025 – **IEEE MetroAgriFor 2025** – 2025 IEEE International Workshop on Metrology for Agriculture and Forestry, *2 talks*, Bologna, Italien
18/11/2025 – **euspen SIC 2025** – euspen Special Interest Conference: Precision & Performance 2025 (combining MATADOR, LAMDAMAP & Thermal Issues), *2 talks*, Cranfield, UK

Workshops / IMMS as host, organiser or co-initiator

21/01/2025 – **2nd Central German Digital Day 2025** – networking event for all stakeholders in the fruit-growing sector in the region, *workshop*, Leipzig
22/01/2025 – **Climate Café** – Conservation of resources and a sustainable circular economy – Using AI to achieve greater sustainability and energy efficiency, *SME Digital project offering, co organisor and talk*,online
18/02/2025 – **MD's & DGQ's Start to the Year** – The Ilmenau SME Digital Centre and the German Society for Quality (DGQ) on digitalisation in quality assurance, *SME Digital project offering, talk, event at IMMS*, Ilmenau

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06/03/2025 – AI Breakfast in Ilmenau – Possibilities and limitations of using AI, *SME Digital project offering, co-organisor, talk,* Ilmenau

03/04/2025 – Girls'Day 2025 – What exactly does a research institute do, and what is a typical working day like for a female engineer?, *event at IMMS,* Ilmenau

13/05/2025 – AI Regulars' Table – Model Context Protocol (MCP) – The 'USB-C interface' for LLM multi-agent systems, *SME Digital project offering, organisation, moderation,* online

21/05/2025 – 'Smart Manufacturing' Industry Forum – Automated and innovative joining, *SME Digital project offering, Co-host and moderation,* Ilmenau

27/05/2025 – MeetUp „Building Agent-Native AI-Applications" – Development and application of CoAgents as production-oriented tools for implementing workflows, *SME Digital project offering, Co-host,* Ilmenau

17/06/2025 – AI Regulars' Table: Generative AI in Practice – The Development and Application of Generative AI in Retail, *SME Digital project offering, Co-host,* Ilmenau

24/06/2025 – Online seminar – Boost your business – Optimising processes with AI! Potential and fundamentals of AI readiness, *SME Digital project offering, co-organisor, talk,* online

21/08/2025 – 'Smart Manufacturing' Industry Forum – "Retrofitting throughout the production process", *SME Digital project offering, co-organisor,* Erfurt

08/09/2025 – Launch event for the 2025 Cross Cluster Weeks – "Shaping change within the organisation – securing the future", *SME Digital project offering, co-organisor, co-host,* Erfurt

10/09/2025 – IT Security Day Thüringen – "Prepared for the future: recommendations for action and solutions", *SME Digital project offering, co-organisor,* Erfurt

23/09/2025 – edaBarCamp VII – The 7th Sense of EDA, workshop, *co-organisor, moderation,* Böblingen

13/11/2025 – Experts-MeetUp – Automation in production: plastics technology meets sensor technology, approaches to research collaboration, *SME Digital project offering, co-organisor, talk,* Geschwenda

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› Integrated sensor systems
› Distributed measurement + test systems
› nm-precise 6D direct drives
› Contents
* Funding

11/03/2025 – **embedded world 2025** – embedded world Exhibition & Conference 2025, meeting place for the embedded community, *exhibition booth,* Nürnberg

11/03/2025 – **AI Day for SMEs** – BVMW e.V. Thüringen and ITnet Thüringen e.V. as part of the Thüringen Exhibition, *talk, exhibition booth*, Erfurt

02/04/2025 – **Entrepreneurs' Morning** – SaaleWirtschaft e.V., *talk, exhibition booth,* Rudolstadt

09/04/2025 – **WID 2025** – World Interferometry Day, *poster, exhibition booth,* Ilmenau

23/04/2025 – **IT-KOM 2025** – Careers Fair for the Applied Computer Science programme at Erfurt University of Applied Sciences, *exhibition booth*, Erfurt

07/05/2025 – **InnoCON 2025** – Thüringen's flagship event on innovation policy: 'Key technologies: paving the way for tomorrow's world', *exhibition booth*, Ilmenau

08/05/2025 – **COnnections 2025** – Coburg University of Applied Sciences Job and Careers Fair, *exhibition booth*, Coburg

18/06/2025 – **Canitz Eco-Field Days** – A meeting place for the agriculture of tomorrow, *poster, demonstrators*, Canitz

25/08/2025 – **ISSOM 2025** – International Summer School on Microelectronics, *lecture, exhibition booth,* Hannover

27/08/2025 – **17th Erfurt Technology Dialogue** – "Towards sustainable production with the digital twin", *exhibition booth,* Erfurt

28/08/2025 – **ThEx Annual Conference on the Economy of the Future** – "Shaping the future – experiencing sustainability", *exhibition booth,* Jena

22/09/2025 – **Mechanical Engineering Day Thüringen 2025** – Manufacturing of the future: automated, connected and collaborative, *exhibition booth,* Erfurt

01/10/2025 – **7th AI Forum Thüringen** – Networking, practical applicability and the future viability of artificial intelligence, *exhibition booth,* Erfurt

21/10/2025 – **elmug4future 2025** – Measurement Technology for Life Sciences: Markets, Requirements and Solutions, *talk, exhibition booth,* Jena

28/10/2025 – **inova 2025** – The Careers Forum at Technische Universität Ilmenau, *exhibition booth,* Ilmenau

12/11/2025 – **TUCconnect 2025** – The Careers Fair at Technische Universität Chemnitz, *exhibition booth,* Chemnitz

01/12/2025 – **Master Meets Machine Crafts Festival** – Conference and exhibition featuring automation and robotics solutions, *exhibition booth,* Erfurt

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High-precision labs reorganised for research down to the picometre; *https://youtu.be/XiQR5vMODg4*

AWARE: Energy-efficient edge AI sensor system for industrial monitoring applications; *https://youtu.be/Yv-XzoZxICQ and https://www.linkedin.com/feed/update/urn:li:activity:7305144446898110464*

ScoreChip: developing a SPAD-based line sensor for chemiluminescence detection; *https://youtu.be/OlVMcomHenM*

Visit by the Conference of Medical Technology Student Unions in Erfurt; *https://www.linkedin.com/feed/update/urn:li:activity:7333125118602235906*

Season's greetings; *https://youtube.com/shorts/zRJNL3qGUmY and https://www.linkedin.com/feed/update/urn:li:activity:7407412380822999040*

Reviewed publications

Case Study on Compression of Vibration Data for Distributed Wireless Condition Monitoring Systems, Rick Pandey[1]. Felix Grimm[2,3]. Dominik Nille[2]. Christoph Böckenhoff[2]. Jonathan Gamez[1]. Sebastian Uziel[1]. Albert Dorneich[2]. Tino Hutschenreuther[1]. Silvia Krug[1,4]. *Applied Sciences 2025, 15, 12346.* **DOI: doi.org/10.3390/app152212346.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Balluff GmbH, Zabergäustraße 8, 73765 Neuhausen auf den Fildern, Germany. [3]University of Stuttgart, Institute of Smart Sensors (IIS), Pfaffenwaldring 47, 70569 Stuttgart, Germany. [4]Mid Sweden University, Department of Computer and Electrical Engineering, Holmgatan 10, 851 70 Sundsvall, Sweden.

Quantization Compensator Network: Server-Side Feature Reconstruction in Partitioned IoT Systems, Isaac Sánchez Leal[1]. Oscar Artur Bernd Berg[1]. Silvia Krug[1,2]. Eiraj Saqib[1]. Irida Shallari[1]. Axel Jantsch[1,3]. Mattias O'Nils[1]. Tomas Nordström[4,5]. *in IEEE Access, vol. 13, pp. 186488 – 186508, 2025,* **DOI: doi.org/10.1109/ACCESS.2025.3627072.** [1]Mid Sweden University, Department of Computer and Electrical Engineering, Holmgatan 10, 851 70 Sundsvall, Sweden. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [3]Technische Universität Wien, Christian Doppler Laboratory for Embedded Machine Learning, Institute of Computer Technology, Gußhausstraße 27-29, 1040 Vienna, Austria. [4]Umeå University, Department of Applied Physics and Electronics, 901 87 Umeå, Sweden. [5]Research Institutes of Sweden (RISE), Högskolan i Borås, 501 90 Borås, Sverige.

Suitability of Radio Communication Technologies for Smart Orchards Considering Seasonal Effects, Silvia Krug[1,2]. Falk Eisenreich[1]. Tino Hutschenreuther[1]. *2025 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), October 28 – 30, 2025, Bologna, Italy.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Mid Sweden University, Department of Computer and Electrical Engineering, Holmgatan 10, 851 70 Sundsvall, Sweden.

Out-of-Band Over-The-Air-Update for LoRaWAN-based Sensor Networks using BLE, Florian Jung[1]. Silvia Krug[1,2]. Tino Hutschenreuther[1]. *2025 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), October 28 – 30, 2025, Bologna, Italy.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Mid Sweden University, Department of Computer and Electrical Engineering, Holmgatan 10, 851 70 Sundsvall, Sweden.

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Abbreviations

6D *6 degrees of freedom*

AC *alternating current*
ADC *analog-to-digital converter*
AFE *analog frontend*
AI *artificial intelligence*
ASIC *application-specific integrated circuit*

BLE *bluetooth low energy*

CMOS *complementary metal–oxide semiconductor*
CFD *computational fluid dynamics*
CNN *convolutional neural network*
CSV *comma-seperated values*
CTW *contact wall module*

DC *direct current*
DOFs *degrees of freedom*

EDA *electronic design automation*
EDP *expert design plan*

FD *floating diffusion*
FFT *fast Fourier transformation*
FPGA *field programmable gate array*

I²C *inter-integrated circuit*
IC *integrated circuit*
IIP *intelligent-IP*
IoT *internet of things*

LFA *lateral flow assay*

NPS *nanopositioning system*

PCB *printed circuit board*
PINN *physically informed neural network*

QSPI *quad serial peripheral interface*
RAM *random-access memory*

SME *small and medium-sized enterprises*
SPAD *single-photon avalanche diode*
SRAM *static random-access memory*

TSN *time-sensitive networking*
TSV *through-silicon via*

ULP *ultra-low power*

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