IMMS

ANNUAL REPORT

2024

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

MICROELECTRONICS

MECHATRONICS

EMBEDDED SYSTEMS

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

Integrated **sensor systems**

Smart distributed **measurement and test 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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www.imms.de/annualreports

Frontispiece: Chip with optimised lock-in pixel technology developed by the TIRELESS research group, shown here on a circuit board for application tests in a lateral flow test strip reader. Photograph: IMMS.

Ralf Sommer and Martin Eberhardt. Photograph: IMMS.

Dear reades,

In 2024, we completed our internal research groups “TIRELESS”, “AI” and “NextGen-Pos”. These research groups, which are funded by the German Land of Thüringen, are an important building block for the further development and realisation of IMMS’ strategic goals and for transfer projects with companies. These groups work on basic principles and initiate new research and development projects for the long-term strategic orientation of the institute. We present the results to you in this report. We are delighted that Thüringen will continue to support IMMS research from 2025 with “VirtuSen”, an internal research group. This will enable young researchers to focus on doctoral topics relating to the application of AI-based virtual sensor technology to effectively increase the precision of positioning systems.

www.imms.de/virtusen

To our delight, one of our employees was not only awarded an iENA silver medal for his patent, he also successfully defended his dissertation on a new control concept for sub-nanometre-precise positioning developed in the NanoFab research training group.

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* Funding

We used 2024 intensively to achieve important milestones in our research and thus refine the content of our three strategic research fields of “Integrated sensor systems”, “Smart distributed measurement and test systems” and “Magnetic 6D direct drives with nm precision”. This report highlights a selection of these. For example, we have implemented solutions for anomaly detection with edge AI and unsupervised learning for smart machine monitoring that reduce effort and increase benefits for users; we have developed methods for the design, architecture and modelling of trustworthy electronic systems; we have found ways to efficiently merge heterogeneous data for comprehensive analyses in agriculture and beyond; we have developed a direct drive system controlled in six dimensions for nanometre-precise positioning in a motion range of 200 mm diameter to 25 mm height and further advanced the modelling of electrodynamic energy harvesters.

www.imms.de/research

These and other solutions are made possible by performance and funding. We would like to thank the German Land of Thüringen for its institutional funding, which makes our transfer work and cooperation with Thuringian SMEs possible in the first place. We would like to thank our committees for their support and advice in all matters. We would also like to thank all our research partners for their manifold impulses, which we transfer into application-orientated solutions. We would also like to thank our business partners and sponsors as well as all those who encourage us in our endeavours.

We would like to thank our employees for their commitment, their creative ideas and their performance; this leads to the innovative solutions that our partners value. You can find examples of this in our report. We wish you an exciting reading experience.

www.imms.de/annualreports

Ralf Sommer
Scientific Managing Director

Martin Eberhardt
Financial Managing Director

Internal research groups at IMMS

An important pillar for the further development and fulfilment of the strategic goals of IMMS are its internal research groups, which are financed through institutional funding from the German Land of Thüringen. These groups work on fundamental topics, develop innovative technology and are crucial for the expansion and development of new expertise in the areas of integrated sensor systems, smart distributed measurement and test systems and high-precision drives. They contribute to the development and expansion of the scientific basis of IMMS and make it possible to react quickly and innovatively to challenges and thus be prepared for the future. Both this basic research and the initiation of new research and development projects are essential for the long-term strategic orientation of the institute. Independence from funding calls in research groups makes it possible to work continuously on important topics over the long term.

In 2024, important goals were achieved in the TIRELESS, NextGenPos and AI research groups outlined below and the foundations were laid for transfer projects with companies. The foundation was also laid for the next research group, VirtuSen, which is set to start work in 2025. In this group, doctoral students are researching virtual sensor technology and AI to detect and compensate for disruptive influences on complex mechatronic systems such as high-precision drives with spatial resolution.

www.imms.de/virtusen

Internal research group TIRELESS* (Feb/2024 – Feb/2025)

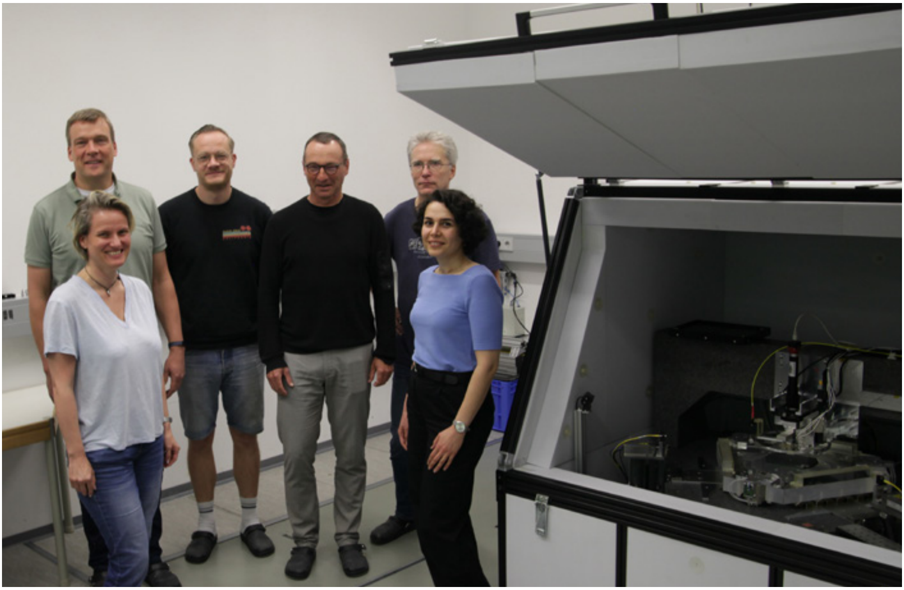
The aim of the TIRELESS research group is to combine the results and new findings from the MEDIKIT, Ovutinin and SensInt projects on time-resolved fluorescence measurement and to develop a new lock-in pixel sensor for reading out lateral flow strip tests.

Fluorescent dyes are used as markers in in-vitro diagnostics, among other things, as they can be easily distinguished from background and interfering signals. Quantitative statements on concentrations and ratios are necessary for many diagnostic questions. Conventional detection systems based on strip tests with classic dye

Representatives of the TIRELESS research group with the developed chip with optimised lock-in pixel technology, here on a circuit board for application tests in a lateral flow test strip reader. Photograph: IMMS.

particles such as gold and strip test readers are not sensitive enough for this. New test strip platforms with fluorescent dyes such as europium offer much higher read-out sensitivities. The lock-in principle, implemented in a chip for the first time in the MEDIKIT project and continued in Ovutinin and SensInt, makes complex optical set-ups in fluorescence test strip readers obsolete. The fluorescent dye is optically excited by a light source and the emitted photons are detected by the sensor chip after the excitation light has decayed. The emitted light can be accumulated over several illumination cycles. This means that even very weak fluorescence can be quantitatively detected, thus achieving higher sensor sensitivities.

The TIRELESS research group also used the X-FAB contact wall module for the first time, researched its influence and achieved greater sensitivity in fluorescence imaging through optimised lock-in pixel technology and an improved light source.



Members of the internal research group NextGenPos with the developed drive system NPS6D200 with implemented laser focus sensor. Photograph: IMMS.

Internal research group NextGenPos3* (Jan/2023 – Dec/2024)

The "Next Generation Positioning – NextGenPos" research group is dedicated to preliminary research into the development of ultra-high-precision magnetic 6D direct drives with the aim of qualifying and establishing such positioning systems for use in the nanometre-precise measurement and structuring of objects. In Phase 3, which has now been completed, work in 2023 and 2024 focused on the systematic characterisation and improvement of positioning performance as well as the further development of overall functionality towards robust industrial applications. In addition to the NPS6D200[1] already developed in phase 2 and described in a technical article in this annual report, a new type of 6D nanopositioning system for a smaller travel range of Ø 100 mm x 10 mm was implemented and used as a research platform for the various detailed investigations.

Zum NPS6D200-Fachartikel

Using the Ø 200 mm x 25 mm system (NPS6D200), a laser focus sensor was successfully implemented as a highly sensitive probing system, thereby realising full

1 *NPS6D200 – A Long Range Nanopositioning Stage with 6D Closed Loop Control, Steffen Hesse. Alex Huaman. Michael Katzschmann. Bianca Leistritz. Ludwig Herzog. Appl. Sci. 2024, 14, 6972. DOI: doi.org/10.3390/app14166972. IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany*

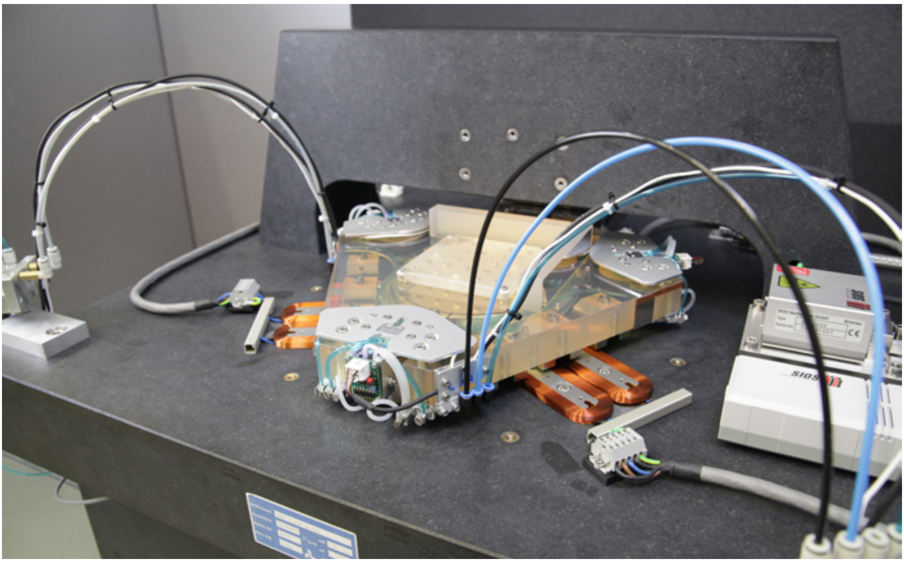
functionality as a complete device that measures with nanometre precision for the first time. In addition, in-situ methods for improving machine metrology were developed using this system and a systematic analysis of the thermal behaviour with an evaluation of the various thermal disturbances was carried out.

Using the newly created NPS6D100 demonstrator, in addition to performance optimisation and the investigation of location-dependent effects, the nanometre-precise operation of such integrated multi-coordinate drives was examined using standard industrial control hardware.

Overall, the research group delivered valuable results on the various detailed aspects and thus laid the foundation for further research projects at IMMS, such as the "NanoFab" research training group and the directly subsequent "VirtuSen" research group. As complex technology demonstrators, the 6D nanopositioning systems which have been built represent versatile research platforms for these ongoing and future IMMS research projects in the field of nanopositioning.

www.imms.de/nanofab

www.imms.de/virtusen



Novel 6D nanopositioning system for a smaller motion range of Ø 100 mm x 10 mm. It was developed by the NextGenPos research group and used as a research platform for various detailed investigations. Photograph: IMMS.

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.

Internal AI* research group (Apr/2021 – Dec/2024)

The AI research group has developed approaches for data pre-processing and AI algorithms whose applications are seen in particular in the monitoring and analysis of industrial processes and in the recording and processing of digital biomarkers.

AI and machine learning can increase efficiency in industry and save a lot of time – but also cost a lot of time until they are ready for use. To significantly reduce this initial effort, IMMS has developed methods and implemented them in two demonstrators. For both scenarios, it was shown that not only is it possible to deploy AI-based monitoring solutions quickly, but that they also work without cloud access and can therefore be used to derive lean monitoring applications. The results are described in detail in a technical article in this annual report.

Zum KI-Fachartikel

Working hand in hand with the Technische Universität Ilmenau

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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 2024, 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 is being 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 is developing 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

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.

www.imms.de/nanofab

IMMS as “Smart Sensor Systems Model Factory” in the “Mittelstand-Digital Zentrum Ilmenau” (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 signalling 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

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**

Demonstrator developed in the VE-ARiS project to validate watermarks as copy protection in chip design.

Photograph: IMMS.

In 2024, the VE-ARiS project was funded by the Federal Ministry of Education and Research under the reference 16ME0242.

SPONSORED BY THE

Federal Ministry
of Education
and Research

"iC-Haus GmbH is a leading German manufacturer of application-specific integrated circuits (ASICs) with 40 years of experience in chip design for industrial, medical and automotive solutions.

Dr. Heiner Flocke, Managing Director of iC-Haus GmbH. Photograph: iC-Haus GmbH.

As part of our VE-ARiS funding project, we were looking for a solution to recognise and prevent counterfeit chips. Thanks to a successful partnership and cooperation, we were able to develop new methods for copy protection at chip level. These are now being implemented directly in practice and make reproduction more difficult and protect against counterfeiting at system level.

www.imms.de/aris

IMMS has contributed to this solution by developing new processes for labelling chips with a watermark. A demonstrator was set up together with all partners in the project to test the functionality and efficiency of the mechanisms developed.

The speciality of the IMMS contribution was the development of innovative methods for chip security. We involved IMMS in our project because we are convinced of the expertise and reliability of the institute due to our long-standing and successful collaboration in other projects such as KI-EDA and FluoResYst.

www.imms.de/ki-eda

www.imms.de/fluoresyst

The collaboration with IMMS was very successful and effective. By sharing expertise and resources, we were able to jointly develop a solution that met and even exceeded the requirements. We greatly appreciate the result and the nature of the collaboration and look forward to further joint projects in the future."

www.imms.de/ref

iC-Haus Integrated Circuits

www.ichaus.com

Mirjam Mantel, Research & Predevelopment Mechatronic Systems & System Integration, Siemens AG. Photograph: Stefan Schmerold, blende11.

"As a Siemens research and development department in the field of mechatronic systems and power electronics components, we are active in the testing of new technology. Our joint work with IMMS in the VE-VIDES project was an important aspect of our research and development. Together, we were able to utilise a RISC-V-based ASIC developed at IMMS to evaluate force sensors. IMMS contributed its expertise in designing trustworthy design structures and led the coordination between the partners to ensure a seamless integration of the work in the consortium.

The close cooperation with IMMS was characterised by a practical and application-oriented approach. This collaboration enabled us to unlock the full potential of the joint funding project and achieve a successful result, which was proven by a system demonstrator.

More in the VE-VIDES article

The partnership has exceeded our expectations and we consider the results to be very successful. The cooperation with IMMS was not only important for the project itself, but also for potential future research and development work.

We see the exchange and collaboration with IMMS as an important step towards developing innovative solutions in trustworthy electronics."

SIEMENS

www.siemens.com

”seioTec is a young Thuringian high-tech company that offers industrial IoT and edge solutions. AI is increasingly being used here. The central challenge of many data-driven and AI-based applications in industry is the acquisition and near-real-time processing of sensor and process data. High-frequency vibration and ultrasonic data offer great potential for various applications, but present major hurdles in terms of device technology implementation.

Frank Seiferth, Managing Director seioTec GmbH. Photograph: Christopher Schmid.

The InSignA Innovation Hub (iHUB) was therefore an ideal opportunity for seioTec to look for innovative solutions to this problem together with its research and development partner IMMS. The jointly developed system architecture and implementation was developed into a proof-of-concept measurement solution, which will now be further tested in various scenarios in collaboration with our customers.

More in the iHub article

In our solution-oriented collaboration with IMMS, we were able to benefit in particular from the expertise of IMMS employees in sensor and embedded systems technology. I look forward to further collaborations with IMMS in the future, which will help us to develop new technology for our products and services and create new marketable solutions.“

www.imms.de/ref

seioTec digital change

www.seitec.info

ENCOURAGEMENT OF YOUNG ACADEMICS

All information on our study-related offers:

www.imms.de/students

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.

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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 expanded

IMMS presented itself at six careers fairs in 2024. That was twice as many as the previous year. The institute drew attention to its high-quality and committed promotion of young talent with newly prepared course-related information. Students from dis-

As here at HAW Hamburg, IMMS 2024 also presented itself at university locations such as Hannover, Hamburg, Duisburg-Essen, Ilmenau and Erfurt.

ciplines such as electrical engineering, mechatronics, computer science and related degree programmes were able to find out about internships, final theses and part-time jobs as well as other opportunities to join the institute. The long-term practical training that accompanies the degree programme with challenging topics, individual support and industrial-standard equipment prepares students for a career in industry and application-oriented research. The aim is to strengthen companies in the region by promoting young talent at IMMS. Positive student feedback on the variety of topics on offer and the customised support provided was received at the careers fairs at Technische Universität Ilmenau and Erfurt University of Applied Sciences as well as at university locations such as Hannover, Hamburg and Duisburg-Essen.

Long Night of Science in Erfurt for career guidance

IMMS also used the Long Night of Science in Erfurt on 8 November to provide information about its offers to promote young talent and to get children interested in technical content through hands-on activities with a fun factor. As part of the Erfurt Research and Industry Centre (Forschungs- und Industriezentrum Erfurt e.V., FiZ), IMMS coordinated the package of activities with partners in Erfurt South-East for the Erfurt Science Night. The Technische Universität Ilmenau, the Ernst Abbe University of Applied Sciences Jena, the Schmalkalden University of Applied Sciences, the Nordhausen University of Applied Sciences and the Gera-Eisenach Cooperative State

www.imms.de/students

The soldering stations were particularly popular for the Long Night of Science on 8 November 2024 – you could build and test your own Long Night souvenir. Photograph: IMMS.

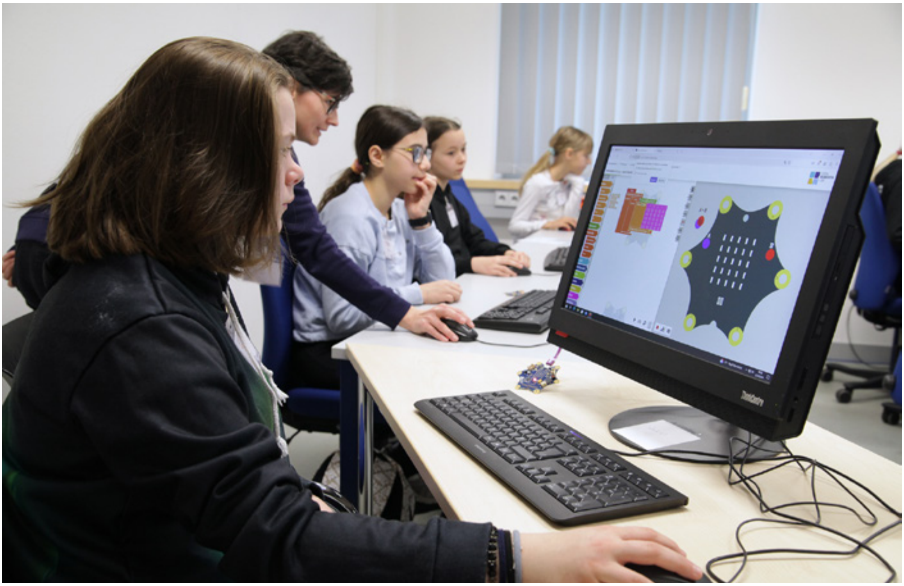
https://youtu.be/yBNx18nzxHQ

University were invited to present their study programmes at various FiZ partners during the Long Night of Science. In doing so, they complemented the FiZ partners' diverse insights into possible future fields of activity in research, development and production for Erfurt school pupils at CiS Forschungsinstitut für Mikrosensorik GmbH, Fraunhofer-Zentrum Erfurt, IBYKUS AG, IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH (IMMS GmbH), Melexis Erfurt GmbH, TÜV Thüringen e.V. and X-FAB Global Services GmbH.

At IMMS, queues formed at the soldering stations, where our young guests were able to patiently solder various kits with different levels of difficulty under expert guidance and proudly take them home with them. IMMS also offered hands-on activities such as the Ilmenau slide race with a self-sufficient energy supply from vibrations. Those with a sweet tooth were able to carry out pH tests and enjoy them without tooth decay. Visitors could test a chip for mobile diagnostic systems to detect diseases using time-resolved fluorescence measurements, read a mobile phone from their hand and test sensor patches or inspect the autonomous miniature transporter at the TU Ilmenau stand and find out about the courses on offer.

All in all, Erfurt South-East was packed full of eye-catching fun hands-on activities, eye-opening moments and plenty of career and study guidance in the STEM field. According to the FiZ members, the overall programme led to a significantly greater influx of guests than in the previous year.

www.imms.de/students



One of the activities for Girls'Day at IMMS on 25 April 2024: Programming with Open Roberta using the Calliope mini system. Photograph: IMMS.

Girls'Day

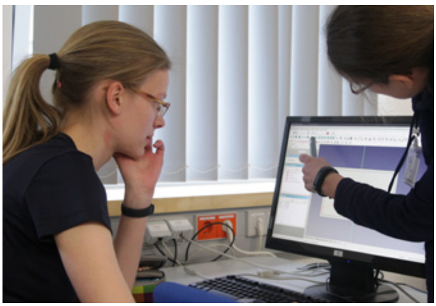
Fraunhofer IDMT, IMMS and TU Ilmenau gave girls from class 5 onwards their first insights into science, research and development on Girls' Day on 25 April 2024. This nationwide career and study orientation event introduces girls to professions or fields of study in which the proportion of women is below 40 percent, such as natural sciences, technology and computer science. At IMMS, 17 girls from class 5 to 8 used this opportunity to find out what vibrations are capable of and how they can be visualised, to write programme code on the Open Roberta platform with the Calliope mini system, to solve small and large tricky questions in the puzzle corner and to solder their own torch. The pupils from Goethe-Schule Ilmenau had a lot of fun and were supervised with equal enthusiasm by a team of two engineers and a mathematician from IMMS and student support.

Young people at the IMMS Research Day on 3 April 2024 building and programming a test stand for electromagnetic induction. Photograph: IMMS.

Research day for teenagers

During the Easter holidays on 3 April 2024, IMMS invited pupils to a research day. Nine young people from classes 9 and 10 attended, including some from the specialised STEM secondary schools in Ilmenau, Erfurt and Jena. They took the opportunity to bring the school theory of STEM subjects to life and get a taste of our research institute. They were given an insight into construction and 3D printing, learnt how to build a small circuit and also soldered it. Afterwards, they took care of the construction and programming of a test stand for electromagnetic induction. The eventful day was very well received and organised and supervised with great commitment by the Girls'Day team. A repeat is planned for the autumn holidays in 2025.

At the Research Day on 3 April 2024, young people were able to build, solder and program circuits. Photographs: IMMS.



Participants of the edaBarCamp 2024 at the host Infineon in Neubiberg/München. Photograph: IMMS.

edaBarCamp

In September 2024, the edaBarCamp series entered a new round, this time at the host Infineon in Neubiberg/München for session pitches, networking and discussions in the areas of open-source EDA, AI for EDA and verification, chiplets, reuse, hardware/software co-design and automotive. The series of events initiated and organised by edacentrum, OFFIS and IMMS in 2016 regularly hosts interactive and open research meetings based on the BarCamp principle.

Interested parties from the university environment, from degree programmes to professorships, from industry and the public sector as well as anyone interested in electronic design automation (EDA), microelectronics and system design can take part. The edaBarCamp series has its origins in the cross-institute doctoral seminars of the ANCONA project, in which IMMS played a key role.

www.imms.de/barcamp

More visibility for young students in Ilmenau

https://youtu.be/g43-D-yKcxU

In June 2024, there was a change of perspective on a new scale and more visibility at the request of students: ”People should see the cool things you do as soon as they walk across the Ilmenau TU campus and that you can grow with IMMS.“ The result: the largest “circuit board” that IMMS has ever designed.

Video: IMMS.

Adrian Pitterling, M.Sc., scientist at IMMS

"I first came into contact with IMMS through conversations with fellow students and through Prof Sommer's lectures during my studies at Ilmenau TU. These first impressions encouraged me to get to know the institute better. Direct links to the institute then arose through the opportunity to complete a specialist internship and my Bachelor's thesis with Dr Georg Gläser, with close collaboration with Ilmenau TU on the topics. This early experience showed me how I could apply the skills I had learnt during my studies in practice.

After completing my Bachelor's degree, IMMS enabled me to continue working on projects as a part-time research assistant alongside my Master's degree. In the VE-ARiS project in particular, I was able to directly apply and deepen the knowledge I had learnt during my studies. I was able to combine the theoretical foundations from my specialisation in 'Cognitive Technical Systems' with practical challenges and further develop my skills. Working on this project was an ideal complement to my degree programme and prepared me perfectly for my Master's thesis.

www.imms.de/aidesigntest

My Master's thesis entitled 'LLM-based Top-Down Refinement Flow' built directly on the experience and knowledge gained from my work as a research assistant and the

www.imms.de/immsvoices

Adrian Pitterling, M.Sc., scientist in the Microelectronics department at IMMS.

Photograph: IMMS.

knowledge acquired during my Master's programme. After completing my Master's degree, I was able to continue my work at IMMS and now I work full-time as scientific staff member. IMMS offers me the ideal environment to advance my scientific career and work on exciting projects. The positive atmosphere in the team and the opportunity for professional development make IMMS an ideal workplace for me."

Bipasha Roy, M.Sc., scientist at IMMS

"I started my journey in IMMS in 2022, and since 2023 as a researcher in the System Design department. I started as a student assistant and continued with my Master's thesis in the Microelectronics department, where I worked with chip image data to identify different regions on the chip and recreation of the GDSII layout. The work during my thesis not only gave me a deeper understanding of AI application in industrial scenarios but also helped me to gain valuable insights into the structure and creation of microchips. Gaining hands-on professional experience motivated me to continue working in applied research.

www.imms.de/aidesigntest

As a researcher in the System Design team, my focus is on the application of Artificial Intelligence in industrial environments. I find great fulfillment working in the intersection of academic research and real-world implementation where innovative ideas become practical solutions. Our team collaborates closely with both industrial and scientific partners, this constantly introduces new challenges and encourages creative thinking.

www.imms.de/immsvoices

www.imms.de/embeddedai

Bipasha Roy, scientist in the System Design department at IMMS.

Photograph: IMMS.

My initial work at IMMS gave me the opportunity to work on signal processing and find AI-based solutions on embedded systems for anomaly detection – supporting machine health estimation and fault diagnosis in running machinery. My research involved analysing different models on vibration data, to predict and localise defects in bearing systems. My focus and work at IMMS continues to expand towards direction on data-driven optimisation for injection molding machines, where I develop AI techniques to enhance process efficiency.

At IMMS I not only develop AI models, I also contribute to work in other industrial applications where intelligent solutions are implemented. This has allowed me to expand my technical skills, while deepen my understanding of how smart systems can transform manufacturing processes.

Beyond technical challenges, IMMS stands out for its open and collaborative culture. Thanks to my colleagues, working at IMMS is very convenient with high team spirit and active knowledge sharing. At IMMS, I continue to grow – professionally, by exploring cutting-edge AI applications, and personally, through teamwork and shared motivation. I look forward to the journey ahead, filled with new ideas, evolving technologies, and the inspiring people I work with every day.“

www.imms.de/i40

www.imms.de/embeddedai

www.imms.de/immsvoices

Dr.-Ing. David Schreiber, scientist in the Microelectronics department at IMMS, team Mixed-Signal IC Verification. Photograph: IMMS.

Dr.-Ing. David Schreiber, scientist at IMMS

"During my studies and my doctoral research, I often had the opportunity to interact with IMMS employees. We quickly discovered that we had common interests, especially in the field of electronic design automation. So, in 2022, I joined the IMMS microelectronics team at the Erfurt site. At that time, a new team was being formed with a focus on the verification of mixed-signal circuits. Thanks to my previous work in the field of analog circuit design automation and circuit simulation, I was quickly able to contribute valuable insights. Especially after my time in the university research environment, the high frequency of regular chip designs and their tape-outs was an exciting and welcome challenge.

The daily business at IMMS includes both research tasks in funded projects and industrial contracts. This combination provides a significant amount of innovative research activities in the field of chip design, from which industrial clients benefit directly. In my opinion, the team responsible for verifying these chips has the best view of the overall system in which the chips will later be used. At the same time, it is necessary to understand the system in detail. I see this activity as a kind of link between the various disciplines of chip design, such as system architecture, analog design, digital design and characterisation.

I felt comfortable in the IMMS team from the very first moment. Good communication and a relaxed working environment result in an efficient and fulfilling work culture. Everyone in the team is always willing to support each other with their respective specialist skills. From the outset, I was particularly impressed by how much energy is invested in promoting young talent and supporting students. Since most of the employees have followed this career path themselves, it is clear that it is worthwhile. Personally, I would choose this job again anytime."

www.imms.de/immsvoices

RESEARCH FIELD

INTEGRATED SENSOR SYSTEMS

For a flexible microfluidic scanner platform for the cost-effective detection of biochemical reactions, IMMS is developing a SPAD-based line sensor for chemiluminescence detection in the ScoreChip project. The image shows the design for a test system with a light-tight housing. The planned system components can be seen in the video at https://youtu.be/0lVMcomHenM. Graphic: IMMS.

Funded by
the European Union

Freistaat
Thüringen

The joint project “Modular platform for point-of-care diagnostics using the example of sepsis diagnostics parameters” 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 Dynamik and co-financed by the European Union under the joint project number 1001607, the sub-project “Development of a microfluidic scanner for PoC applications based on SPAD sensors” under the reference 2024 VFE 0059.

Research field: **Integrated sensor systems**

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

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

ScoreChip* project launched: modular platform for point-of-care diagnostics using the example of sepsis diagnostics parameters

Challenges for chemiluminescence-based point-of-care devices

To enable the earliest possible treatment to be initiated for sepsis or other clinical pictures, a fast and precise diagnosis is to be established on site without laboratory waiting times. Relevant analytes such as cytokines can be determined using chemiluminescence, for example. These detection reactions produce short, weak flashes of light or a long, weak glow, which is generally not visible to the human eye. In laboratories, the smallest quantities of analytes can be determined via chemiluminescence immunoassays (CLIA) using photomultiplier tubes (PMTs). PMTs are state of the art for low-light sensing, especially for laboratory analysers and central laboratories. PMTs are highly sensitive, but only offer pixel-by-pixel spatial resolution using a two-axis scanning method. Compared to integrated CMOS sensors, they are large and expensive, difficult to miniaturise and integrate with complex electronics or microfluidics. As a result, chemiluminescence-based point-of-care tests tend to be the exception in cost-sensitive applications, although they can achieve high sensitivity and test quality.

www.imms.de/ivd

Novel modular microfluidic scanner platform for chemiluminescence

In the ScoreChip project, a novel microfluidic scanner platform is being developed for on-site diagnostics of analytes using chemiluminescence. The aim is to visualise biochemical reactions directly from clinical samples, offering an previously unachievable combination of spatial resolution and sensitivity. The new solution revolutionises the PMT approach by scanning fluidic chips with spatial resolution on only one axis instead of two, while offering comparable sensitivity – but at a significantly lower cost.

www.imms.de/scorechip

SPAD technology for faster and more precise diagnoses

The core of the system is a CMOS sensor based on single-photon avalanche diodes (SPADs). SPADs can resolve individual photons and recognise the extremely weak light signals of chemiluminescence, which are generated by biochemical reactions. If required, the platform can be supplemented by an external fluidic control system from the project partners, which makes the measuring system flexible and universally applicable. The development not only enables high-resolution analysis of samples, but also simple adaptation to different diagnostic applications such as sepsis screening.

IMMS opens up SPAD technology for chemiluminescence-based point-of-care diagnostics

IMMS is contributing its extensive experience in the design and manufacture of opto-electronic CMOS sensors to the project. The development of a customised SPAD line sensor achieves a combination of sensitivity and spatial resolution that has never been achieved before. The work includes the design, verification and testing of the sensors as well as the integration into the scanner platform.

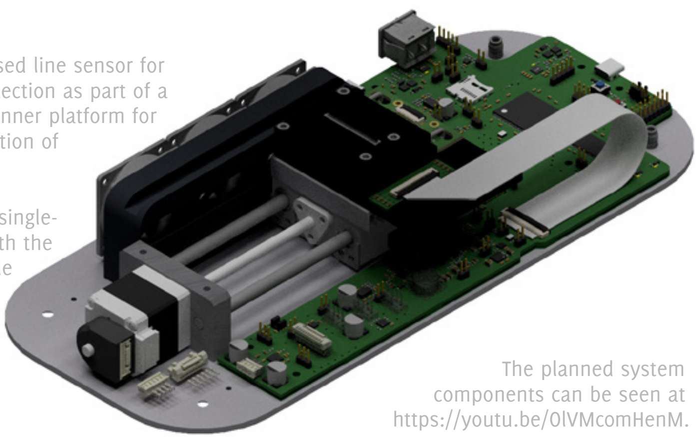
Flexibility and cost-effectiveness as key features

Together with the partners' solutions, the microfluidic scanner platform not only offers a more cost-effective alternative to existing systems, but also significantly greater flexibility. Clinics and laboratories can customise the system and thus open up new diagnostic possibilities. This makes the solution particularly interesting for point-of-care applications where speed and precision are crucial.

www.imms.de/scorechip

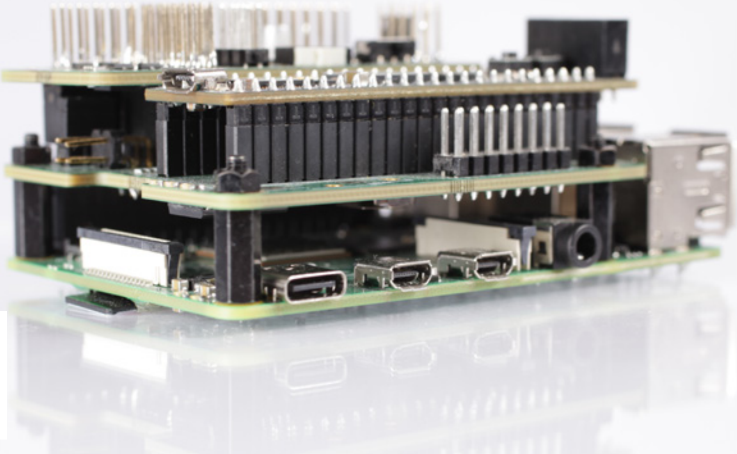
Design for the SPAD-based line sensor for chemiluminescence detection as part of a flexible microfluidic scanner platform for the cost-effective detection of biochemical reactions.

The graphic shows the single-axis scanner system with the SPAD line sensor module with linear SELFOC® lens arrangement on top.



Graphic: IMMS.

The planned system components can be seen at https://youtu.be/0lVMcomHenM.



One of the demonstrators developed in ARiS to validate the watermarks as copy protection in chip design.

Photograph: IMMS.

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Completion of the VE-ARiS* project: Copy protection for chips

Copied chips are a problem for manufacturers and users. Manufacturers or design houses design innovative chips with a great deal of expertise and financial investment and suffer economic damage with every copy of these chips. Users cannot rely on the performance parameters of the originals when dealing with copies and therefore potentially risk the safety of their own products.

The copies are created in various ways: a chip can be “rebuilt” on the basis of the data sheet, i.e. a new chip design with approximately the same properties is created. If the circuits themselves are to be imitated, the chips are often analysed using various methods to reproduce the internal structure. In some cases, the chips are polished in small steps and photographed under a microscope and the layouts required for production are then redrawn using these images.

www.imms.de/aidesigntest

In the ARiS project, IMMS has researched methods to make this copying more difficult and thus protect chips against it. Two research directions were pursued: A watermark that can be used to mark original chips was investigated to prevent copying. As with banknotes, a check is incorporated to identify an original. Attacks, such as the delayering of chips, were also the focus of the work. A machine-learning-based attack model was developed at IMMS with which this reverse engineering process can be simulated. On this basis, circuit components can be found that are easy to copy and can be “hardened” in the next step. This involves using structures that are difficult to recognise. The investigated approaches to copy protection were successfully validated using various demonstrators.

www.imms.de/aris

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In DI-Meta-X, IMMS is developing an open-source software package based on Python that can be used to read in and specifically modify digital circuits.

Photograph: IMMS.

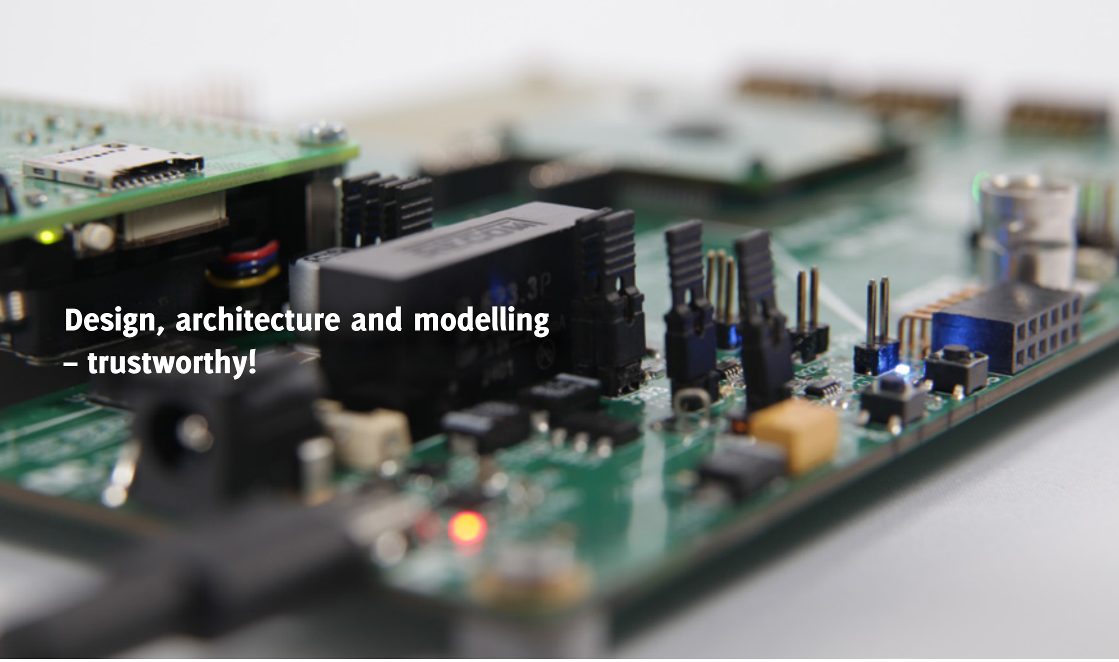
DI-Meta-X* project started: innovative open source tools for new chips

Open source design tools can make it easier for small and medium-sized companies in particular to get started in chip design – no licence agreements need to be concluded and the financial risk can be kept low. However, these software solutions are often difficult to use and are not very suitable for designing low-power chips, for example. IMMS is developing new tools to make open source chip design more widely applicable.

To this end, IMMS is developing a Python-based software package with which digital circuits can be read in and specifically modified. For example, so-called clock gates are to be inserted to switch the clock signal on and off in individual parts of the circuit and thus make the chips more economical. However, the scope of this package is broader and provides a basis for many other optimisations: Logic locking for IP protection or the targeted replacement of circuit parts with more efficient structures can be realised with this package. The aim is to open up new functions for applications and at the same time give research the opportunity to develop new methods in an application-oriented manner.

Together with X-FAB, IMMS is working on a solution with which the open source tools can be easily installed and used in a separate environment. To this end, IMMS is testing the function in its own design environment, integrating new methods for more economical chips and developing a reference design for industrial use.

www.imms.de/meta-x



Design, architecture and modelling – trustworthy!

Demonstrator setup for the first RiscV at IMMS, a chip with open source instruction set architecture. This chip was developed in the VE-VIDES project for a demonstrator from Siemens. Photograph: IMMS.

Go to Siemens statement

Motivation and overview

The development of modern electronic systems is a complex task in which the focus is not only on performance and efficiency, but also on the safety and reliability of the components used. At the heart of the VE-VIDES project was the question of how to ensure the reliability of our mixed-signal systems when different components from different design environments have to be integrated with each other. The challenge was to identify weak points in the early stages of development and overcome them using innovative methods. The aim was to create a solid foundation for future systems that also function reliably in demanding applications such as robotics or industrial automation.

www.imms.de/vides

Field of application, challenges and solutions

The security of chips depends heavily on the quality of the IP used, i.e. the individual components. These are often complex building blocks that need to be verified at various levels. Traditional approaches, which define a narrowly defined verification phase in the design process, offer a certain degree of security, but also limitations. In particular, short-term changes before handover to (prototype) production are a

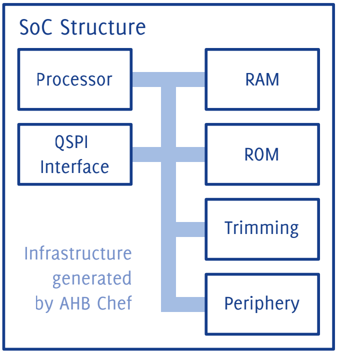


Figure 1:

The AHB Chef generates the Verilog code for the on-chip infrastructure (light blue) as well as the necessary documentation and definitions for firmware development.

Graphic: IMMS.

risk and design errors found in the chip can only be transferred back to a simulation with additional effort to analyse them in more detail. A new approach was therefore adopted: the integration of test mechanisms directly into the design process using generators for digital infrastructure and automated test procedures. At the same time, the focus was on developing tools to optimise IP management and ensure the consistency of designs. These approaches make it possible to guarantee the security of systems from the design level through to production.

Infrastructure: The road network of ASICs

The development of modern integrated circuits is like building a city: it requires not only individual buildings, but also a reliable road network that enables the exchange of data. This exchange takes place via so-called bus systems. Such a structure is shown in Figure 1. Interfaces such as I^2C or QSPI are often used for communications between different chips, which only require a few connection lines. Inside, data transmission is achieved by faster systems with more connections. Registers and memories, for example, are connected to these on-chip bus systems, which have different sizes and addresses like houses in a city.

Setting up such an infrastructure is often manual work and only partially supported by tools. The AHB[1] Chef was therefore created in the project, a Python programme with which the hardware code can be generated automatically from a description of the various registers.

1 *AMBA High-performance Bus (AMBA: Advanced Microcontroller Bus Architecture)*

The register definitions are written by hand as a structured text file. They can be stored and versioned in the design repositories. The AHB Chef uses this "recipe" to generate the implementation in SystemVerilog, a hardware description language. Tasks such as assigning addresses and generating initial documentation and header files for verification and programming are taken over by the application.

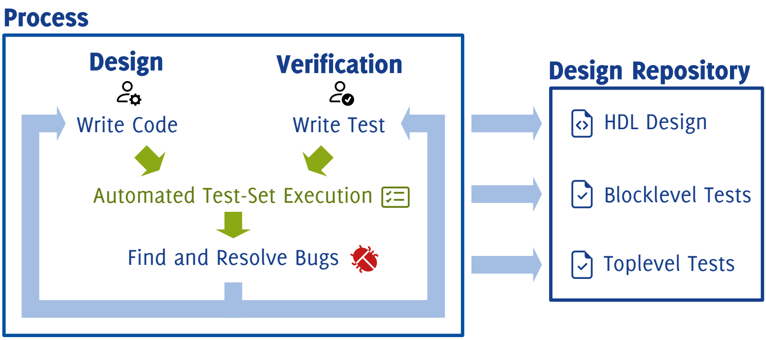
The final result is a finished component that can be used directly in the design. The AHB Chef is used in IMMS designs after the end of the project.

Regression tests in chip design

Verification simulations play a decisive role in chip design at various levels: as production is complex and expensive, as many application scenarios as possible must be tested in the prior verification. This applies to both individual components and the entire chip in the system context. To meet the associated challenges, a regression environment was created in the VIDES project with which test cases can be carried out automatically. The structure is shown in Figure 2. A "library" of test cases is created in each design and each existing component. After each update to the code or design, these test cases can be started automatically and the current status of the design can be assessed. In the course of the design and verification process, this library is expanded and completed bit by bit by design and verification engineers at IMMS. This means that even small, seemingly unproblematic changes in

Figure 2:

The new regression environment allows design and verification engineers to enter their test cases into a shared library and run them automatically. This means that design weaknesses are recognised at a very early stage and can be rectified immediately. Graphic: IMMS.



the design can be tested and verified directly and problems recognised at an early stage without involving verification specialists.

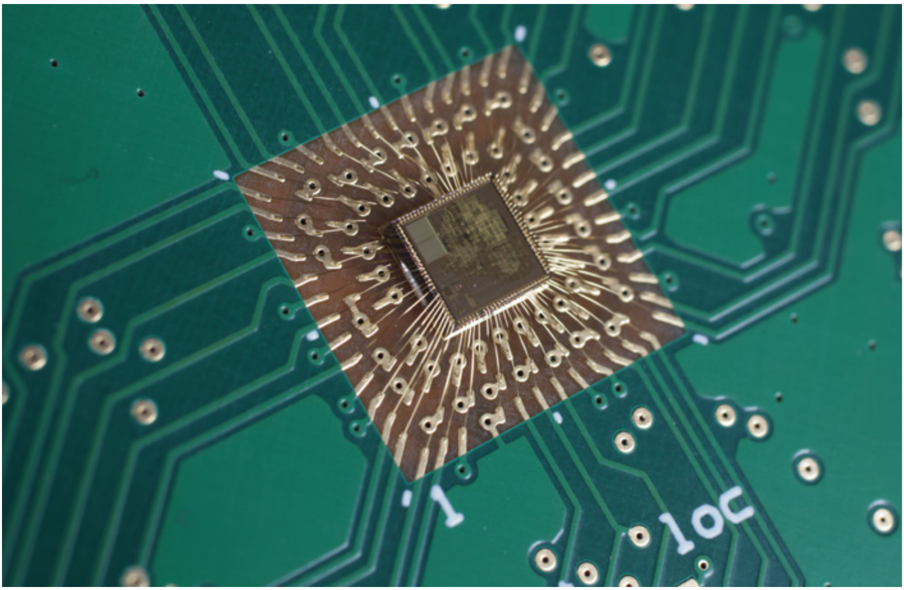
It was important in this test environment that the tests remain applicable in different domains and phases of the design. The environment is designed in such a way that both digital and mixed analog/digital circuits can be considered. In addition, each simulation can be set so that layout effects such as gate delays are also simulated and thus included in the test.

After the end of the project, the environment will be used directly in the chip designs at IMMS and further developed. The execution in FPGA prototypes and the integration of open source simulators are of interest here.

Summary and outlook

The development of trustworthy mixed-signal systems is a complex task, especially when components from different design environments need to be integrated. Traditional verification methods are often insufficient or too complex, as they take place at later stages of the design and last-minute changes before production entail risks. To address these challenges, a new approach has been taken: the integration of ver-

Figure 3: Smart sensor ASIC developed at IMMS for analysing a force sensor. This chip with RiscV processor was designed using the methods shown. Photograph: IMMS.



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

ification mechanisms directly into the design process, complemented by automated tools and test environments.

The methods and tools shown were successfully demonstrated in the project using a smart sensor ASIC that can be used to analyse force sensors. Together with the partners, the chip was put into operation on the circuit board shown in Figure 3.

The VE-VIDES project results will play a major role in IMMS chips in the future: If possible, the new methods will be used right from the end of the project and further developed in follow-up projects.

Contact person: Dr.-Ing. Georg Gläser, georg.glaeser@imms.de

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In 2024, the joint project VE-VIDES was funded by the German Federal Ministry of Education and Research (BMBF) under the reference 16ME0246.

www.imms.de/vides

RESEARCH FIELD

SMART DISTRIBUTED MEASUREMENT AND TEST SYSTEMS

"AWARE" demonstrator (Advanced wireless AI-enabled real-time environment). 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.

youtu.be/Yv-XzoZxICQ

Freistaat Thüringen

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The solutions presented were developed in the internal AI research group at IMMS, which is funded by the German Land of Thüringen, and in the HoLoDEC project.

In 2024, the HoLoDEC project on which this report is based was funded by the German Federal Ministry of Education and Research (BMBF) under the reference 16ME0703. The author is responsible for the content of this publication.

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.

www.imms.de/distributed

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 2024 in our research on smart distributed measurement and test systems

iHUB*: Start-up support for innovative ideas – how start-ups and young companies can benefit from research

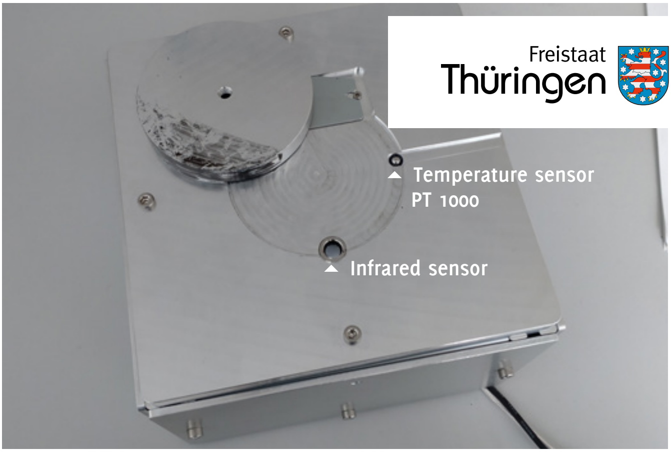
What is iHUB?

As part of the InSignA* performance centre, IMMS is also involved in the iHUB ideas competition as a research partner. 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

iHub competition 2024

In 2024, IMMS was able to take part in the competition as a partner for the first time. The jury selected a total of three project ideas in which IMMS is involved.



Freistaat Thüringen
Thuringian Ministry for Economic Affairs, Science and Digital Society

Figure 1:

Test stand developed at iHub* for process monitoring in a cutting chamber for plastic pulverisation: infrared and temperature sensors were installed here.

Photograph: IMMS.

iHUB projekt LPT – Process monitoring during pulverisation

Task and partner

LPT produces fine powder grains by cutting a long plastic strand with knives. The knives are mounted on a rotating cutter head, which is located in a cutting chamber from which the powder is evacuated. Currently, the cutting process is largely a black box from a process monitoring perspective. Particularly interesting information on the cutting process would be real-time images of the cut itself, e.g. using a high-speed camera, as well as the temperature profile of the components involved in the cutting process, especially the knives, to be able to optimise the process later. The optical solution was developed by Fraunhofer IZFP, while IMMS focussed on temperature measurement.

IMMS solution

To measure the knife temperature, it was first checked whether sensors could be attached directly to the blade. Due to the rotation of the cutter head, only a very small wireless system can be used for this. RFID sensors are the only way to measure there. However, the tested system is not able to transmit the data in real time, which would be necessary for control.

Alternative measurement concepts were therefore developed. Three further options for indirect measurement were identified, two of which were tested on a specially constructed test stand at IMMS, see Figure 1. The temperature of the test objects could be successfully tracked in the laboratory using both methods, see figure 2.

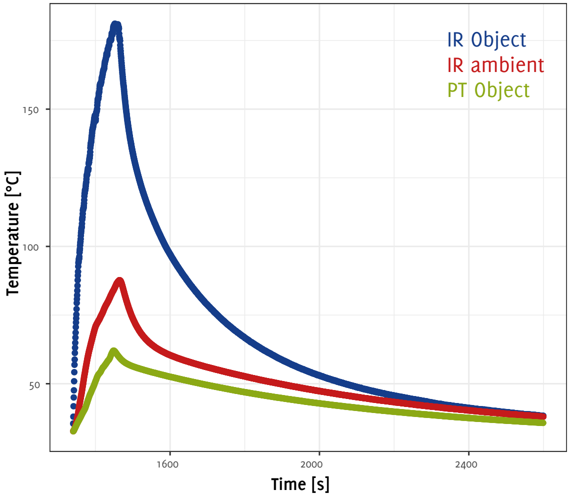


Figure 2:

Comparison of the measured temperature values at various measuring points in the test stand for process monitoring in a cutting chamber for plastic pulverisation.

Graphic: IMMS.

The infrared sensor has proven to be a good option here if positioning in the area of the chamber is possible. Similar properties should be achievable with a fast thermistor. This made it possible to develop a recommendation for measuring the process parameters.

iHUB project KitchenGuard – a new cooking experience with embedded AI

Task and partners

KitchenGuard's vision is to make cooking safer with intelligent sensor technology installed on the oven by using AI to determine what is happening in the cooking pot from acoustic data to prevent fires from starting by switching off in time. The iHUB project aimed to take a first step towards realisation. Fraunhofer IDMT was responsible for designing the microphone arrangement and selecting suitable microphones, while IMMS was responsible for designing the embedded data processing platform.

IMMS solution

The system is to be based on a microcontroller for processing the audio signals. Various options were investigated and the key data compared. The limited resources of embedded systems (MCUs) pose a major challenge when implementing AI models. In particular, the available memory (RAM and flash) and the available computing power must be taken into account. Some variants of current microcontrollers have integrated hardware accelerators for the calculation of neural networks, which should improve capacity. There are also options for reducing the size of the networks and the complexity of the calculations – ideally without negatively impacting accuracy.

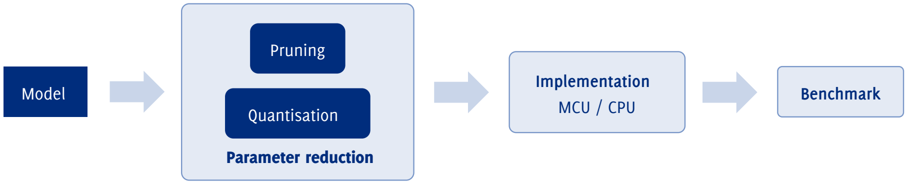


Figure 3: Procedure for the investigation of MCUs with hardware accelerators for neural networks for embedded AI solutions. Graphic: IMMS.

To investigate this, various AI models were tested on an NXP MCXN947 MCU and a more powerful NXP iMX8 CPU with Google TPU and their performance evaluated.

The results show that the hardware accelerator can speed up the calculation time of the neural network by a factor of 8 to 38, depending on the size and structure of the network. The best-performing system with the i-Mx8 application processor offers a strong acceleration (up to 60 times) in the calculation of large networks.

iHUB project PerfML – edge measurement system for distributed signal acquisition in industrial ML applications

Task and partner

seioTec already has an edge platform for ML applications on embedded systems in the form of the datAIndustry app. However, the demand for solutions for vibration and ultrasonic sensor technology and the associated high sampling and data transfer rates is increasing, particularly in distributed systems. The iHUB project therefore aimed to create the conditions for a corresponding system as a proof of concept. In addition to seioTec and IMMS, Fraunhofer IDMT was also involved. The task of IMMS was to design the data transmission efficiently.

Go to seioTec statement

IMMS solution

The partners first developed a suitable system architecture for an edge-capable measurement system for distributed multi-channel signal acquisition and integrated data pre-processing for industrial machine learning applications, see Figure 4. The focus was on the communications interface between the measurement platform and the datAIndustry app. After analysing available technology and protocols in detail, the gRPC framework was chosen as the basis for the data interface between the components. Initial benchmarks have already been carried out with a test configuration consisting of a PC client and server implemented as the respective commu-

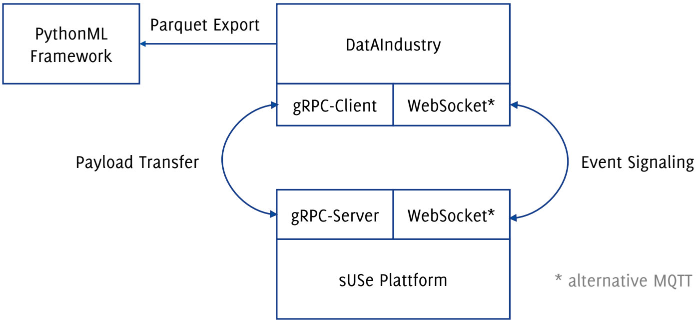


Figure 4:

System architecture for an edge-capable measurement system for distributed multi-channel signal acquisition and integrated data pre-processing for industrial machine learning applications. Graphic: IMMS.

nications counterparts for the two systems. This proved that the transmission of data from several sensors via gRPC over Ethernet is possible without any problems. Packet sizes that are too small have a disadvantageous effect on throughput. Packets that are too large generate a high system load and can lead to problems with the dataIndustry app when storing the data in the internal database. These findings allow seioTec to further optimise its own software. It was also shown that multi-channel measurements with a high sampling rate can be processed by the system and further analyses can be carried out on this basis.

Conclusion on iHUB

In three very different projects, IMMS was able to contribute various competences to support start-ups and young companies in realising their ideas. The institute is ready for the next challenges that companies bring to the iHub competitions.

www.imms.de/ihub

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

Events and information for SMEs

In 2024, IMMS offered as part of the “Smart Sensor Systems Model Factory” at the SME Digital Centre Ilmenau 7 lectures, 16 online seminars, 16 regulars’ tables and 13 specialist workshops as well as 40 consultations on digitalisation to support small and medium-sized enterprises in the introduction of digitalisation and AI solutions. In addition, IMMS was present as the model factory at 19 regional **events** organised by industry networks and trade fairs. There were further 27 activities in the nationwide “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.

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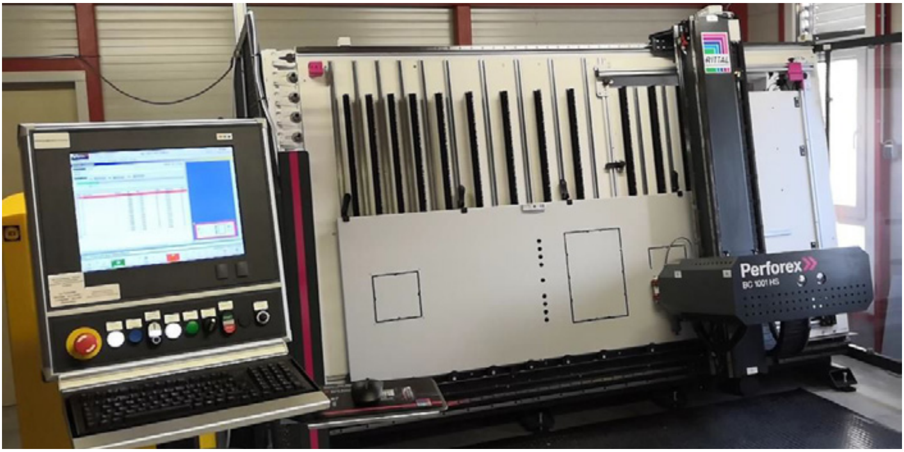
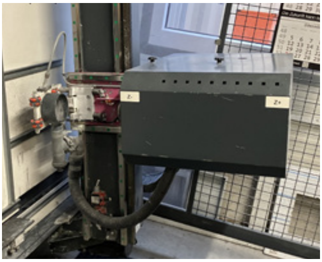
Parallel to the events, 11 **publications** were produced, e.g. on cooperation with companies in projects or on demonstrators, which are distributed to interested parties on the centre’s website, via newsletters and social media.





Milling machine (top), milling spindle (bottom left) and Edge AI measuring system on the milling spindle (bottom right) for wear detection tests on milling tools.

Photographs: HELIRO.

New demonstrators and digitalisation projects

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

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Wear detection on milling tools

The purpose of wear detection on milling tools is, on the one hand, to utilise the tool service life and, on the other hand, to warn skilled workers in good time when the tool is worn to avoid breakages or poor machining results and therefore rejects. Measurement data is recorded on the test setup using vibration sensors in the low kHz range on the tool spindle on the one hand and a mobile ultrasonic measuring device on the other. In several measurement campaigns, data sets were generated, processed and analysed for typical machining processes, materials and tools. Vari-

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ous feature analysis techniques were used. It was found that due to some special boundary conditions, reliable wear detection is not possible with the existing sensor technology. For this reason, new solutions with extended sensor technology and other AI-based evaluation methods were developed for further investigations.

Fill level measurement in a granulate dryer

The aim of the fill level measurement project was to measure and visualise the fill level of plastic granulate in the granulate dryers of injection moulding machines to prevent the dryer containers from "running empty" and thus ensure continuous production. To this end, a concept for the sensors, data processing and transmission technology and visualisation of the measurement data was first developed. Extensive pre-tests with the sensor manufacturer were necessary to verify the suitability of the sensors due to the high operating temperature and the size of the measuring range. These were carried out in 2024 and will be incorporated into the implementation in 2025.

Ultrasound-based diagnostics of engine bearings with AI-based data analysis in an app

The demonstrator for ultrasound-based diagnostics of engine bearings shows a simple option for preventive maintenance in which measurement data is obtained using an air ultrasonic sensor connected to a special mobile ultrasonic measuring device. The sensor is pointed at the engine bearing to be analysed. The recorded noises can then be shown on the device display using a special app that analyses the

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Demonstrator developed at IMMS at the SME Digital Centre Imenau for ultrasound-based diagnosis of motor bearings with AI-based data evaluation in an app.

Photograph: IMMS.

measurement data in real time using AI. A machine learning process is used for the classification; the AI model used for this is based on the deep learning technology Convolutional Neural Networks (CNN). To teach the AI model, measurement data from new engine mounts as well as from mounts with varying degrees of wear and defects were recorded and analysed.

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 Center for Mechanical Engineering (ThZM), the Industry Association of the Plastics Industry (PolymerMat e.V.), the Thuringian Center for Learning Systems and Robotics (TZLR) and the Association of Thuringian AI-Transfer Centers.

digitalzentrum-chemnitz.de

In addition, the SME Digital Centre Ilmenau, together with the one in Chemnitz, the ScaDS.AI Dresden/Leipzig and other partners forms 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.

scads.ai

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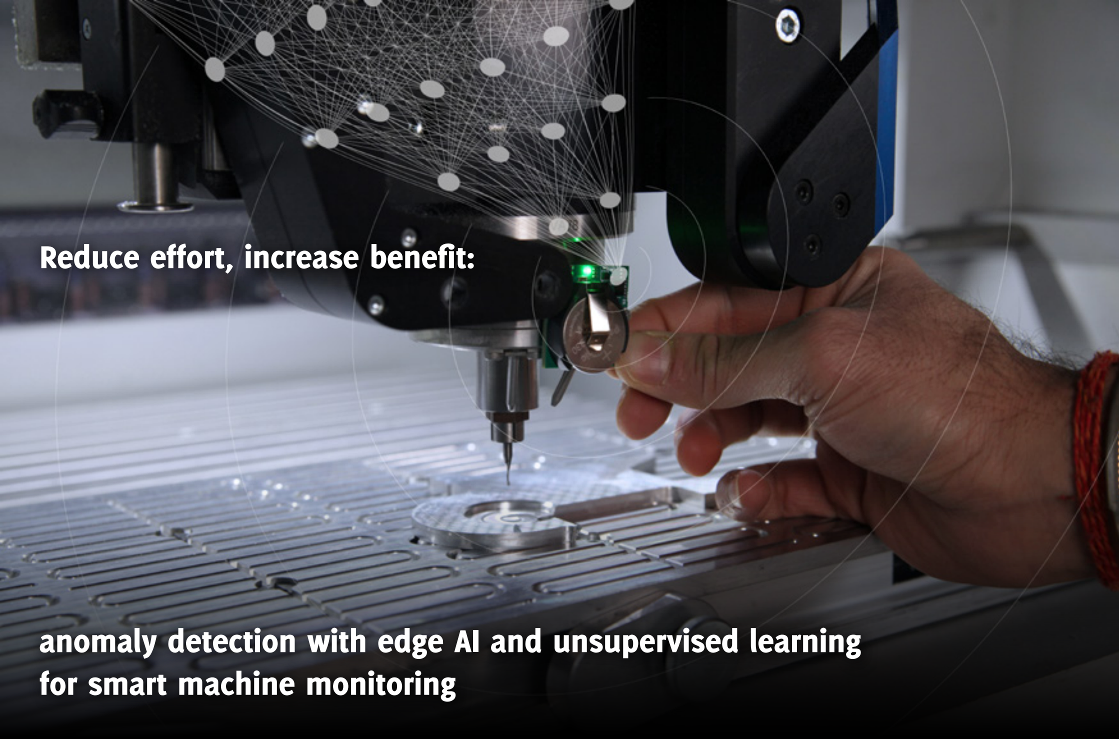

Reduce effort, increase benefit:

anomaly detection with edge AI and unsupervised learning for smart machine monitoring

IMMS has developed energy-efficient edge AI systems with overall system energy modelling for processes, services and systems that can be automated, for example to retrofit existing systems with wireless sensors for condition monitoring or level detection. Photograph: IMMS.

Motivation and overview

AI and machine learning can increase efficiency in industry and save a lot of time – but also cost a lot of time until they are ready for use. To significantly reduce this initial effort, IMMS has developed methods and implemented them in two demonstrators. For both scenarios, it was shown that not only is it possible to deploy AI-based monitoring solutions quickly, but that they also work without cloud access and can therefore be used to derive lean monitoring applications.

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Application area and challenges

For efficient production processes, it is crucial to detect machine faults at an early stage, minimise downtimes and avoid costly repairs. The key to this is continuous monitoring of machine status by usually vibration signals or power consumption. This allows deviations from normal operating behaviour to be detected at an early stage before an actual failure occurs. Especially in combination with modern machine learning methods, complex patterns and small changes can be identified that are not possible with conventional methods.

However, it takes a considerable amount of time and organisation to record sensor data and potential error states with all relevant operating conditions and fault data for training algorithms, especially in industrial applications. In addition, defects on machines occur very rarely or not at all during normal operation while certain error states such as defective bearings and degraded machine parts cannot be easily triggered. Furthermore, the raw data collected usually has to be extensively pre-processed in order to be used for training an AI model.

Solution approaches

To make AI and machine learning accessible to companies' monitoring applications with as little initial effort as possible, IMMS is focussing on unsupervised learning methods. In these methods, a known state, in this case the error-free good state, is recorded and algorithms are used to recognise deviations and initiate appropriate measures. Various methods were investigated for this purpose. A simple algorithm was implemented directly on a small, energy self-sufficient sensor system with local AI and evaluated with a demonstrator for fan monitoring. More complex, more powerful methods were implemented in an energy-efficient edge AI system. The data is pre-processed locally on the sensor node. More complex algorithms, e.g. for anomaly detection, are executed on the edge system, e.g. on a Raspberry Pi. The application is demonstrated by monitoring vibrations on a shaker. The method and sensor arrangement for monitoring the function of a machine component „Verfahren und die Sensoranordnung zum Überwachen einer Funktion eines Bauteiles einer Maschine"[1] has been patented.

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Unsupervised learning

Unsupervised learning is a sub-area of machine learning in which algorithms are used to identify patterns, structures or correlations in data – without any predefined target values or labels. The aim is to extract valuable information from the pure input data, such as groupings, trends or outliers. In other words, anomalous data and machine error states do not have to be recorded in advance. This is achieved with unsupervised learning.

1 *DE 10 2024 100 703 B3, https://register.dpma.de/DPMAregister/pat/register?AKZ=1020241007036*

Typical methods include **clustering algorithms** such as k-Means to group similar data points, **dimensionality reduction** methods such as principal component analysis or singular value decomposition to simplify complex data sets, and **anomaly detection** to detect unusual or unexpected observations. These methods are particularly useful when no or only limited labelled data is available.

Various data sets, some of which are publicly available such as the Pronostia data set[2] were used for further analyses. This involved recording vibration data from bearings.

Data clustering

The k-Means algorithm is a method from the field of unsupervised learning and is primarily used for clustering tasks. Here, data points are divided into k groups so that points within a group are as similar as possible. At the beginning, the algorithm expects the user to provide k so-called cluster centres. It then assigns the nearest centre to each data point and then calculates the new centres of the groups. This process is repeated until the groupings no longer change significantly. K-Means generally works very quickly and is easy to apply to large amounts of data. However, the method can react sensitively to outliers and does not always deliver good results if the data is complex or unevenly distributed.

Data reduction using singular value decomposition and correlation

Figure 1 shows the recorded vibration signals for a bearing from the Pronostia data set. Individual anomalies or deviations from the “intact” status value can be recognised. These may have been caused by external vibrations or similar events. In the Pronostia data set, the analysed bearings were subjected to additional forces so that the bearing wears more quickly. For industrial machines, normal wear can result in 10,000 – 100,000 operating hours, depending on the application. Recording data in the process and pre-processing it for training AI models usually accounts for around 80% of the total effort. To avoid having to pre-process all the raw data at great expense, data reduction makes sense.

2 Nectoux, Patrick & Gouriveau, Rafael & Medjaher, Kamal & Ramasso, Emmanuel & Chebel-Morello, Brigitte & Zerhouni, Noureddine & Varnier, Christophe. (2012). PRONOSTIA: An experimental platform for bearings accelerated degradation tests. Conference on Prognostics and Health Management. 1 – 8.

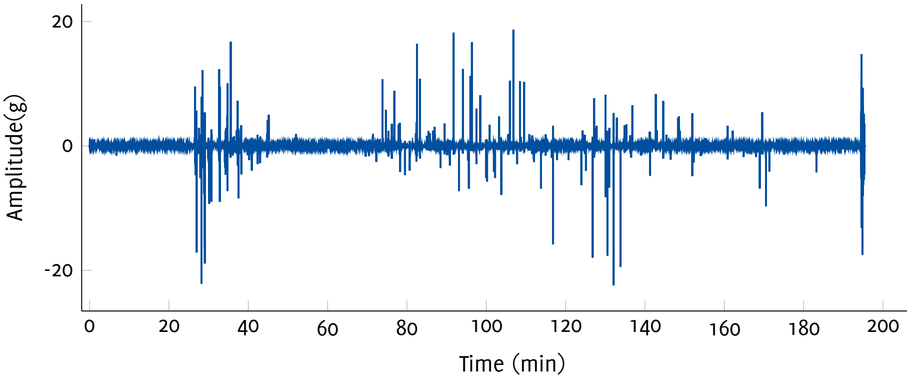


Figure 1: Amplitude curve of a bearing of the Pronostia data set. Graphic: IMMS.

Singular value decomposition

Singular value decomposition (SVD) is a method in linear algebra which is used to exploit the decomposed recorded data matrix for dimensionality reduction. First, the recorded vibration data is converted row by row into a matrix representation. These are then broken down into three separate matrices. The singular value decomposition of a matrix A is usually represented as follows:

$$A = U \Sigma V^T$$

These are:

- ***U:*** The left-hand singular vector matrix. The columns of U are the eigenvectors of the matrix AA^T (covariance matrix).
- ***Σ***: The diagonal matrix of the singular values. The singular values represent the importance of the respective eigenvectors and are arranged on the diagonal of Σ. They are always non-negative.
- ***V^T***: The transposed right singular vector matrix. The columns of V^T are the eigenvectors of the matrix $A^T A$ (covariance matrix).

A reduced data set is obtained by using only the first k dominant singular values and the corresponding parts of $U, \Sigma,$ and V^T. The data points with the largest singular values are shown in Figure 2.

The standard deviation of the singular values was used to calculate a threshold value (Ψ), shown as a dotted line in Figure 2, for the novelty value of the data.

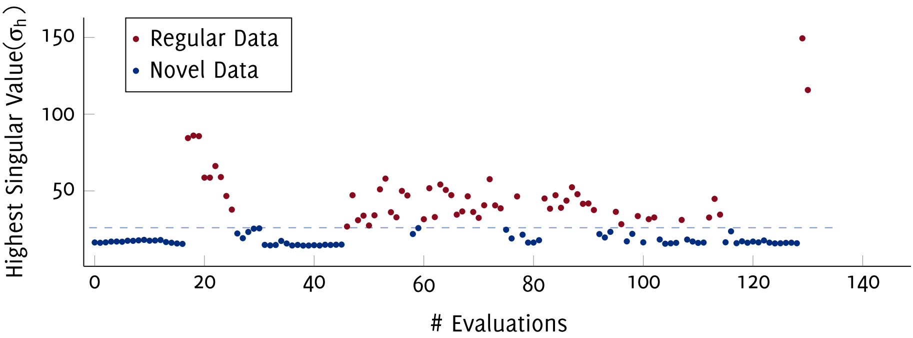


Figure 2: Illustration of the singular values with determined threshold value. Graphic: IMMS.

Correlation

The singular values can be used to recognise deviations from a learned good state. Canonical Crosscorrelation Analysis (CCA) was used as the correlation algorithm and 3 phases were defined for the implementation, see Figure 3:

- Learning Phase
- Observation Phase
- Deployment Phase

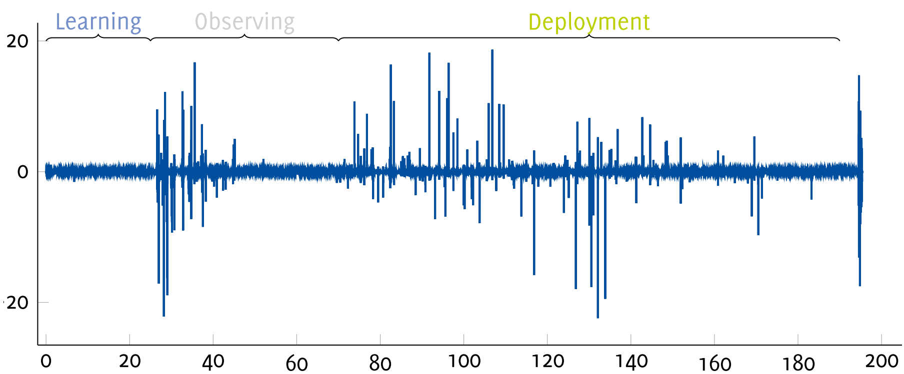


Figure 3: Amplitude curve of a bearing and categorisation into the 3 phases. Graphic: IMMS.

Learning phase

In the learning phase, it is assumed that the machine is in an intact good state. The singular value decomposition is applied to the recorded vibration signal X, which is a 2D transformation of the sensor data. The time-discrete signals of the vector of the singular values, decomposed into frequency components by Fast Fourier Transformation (FFT), are used as a feature for the intact state of the machine and stored in a feature matrix F. Several instances of such a detection and decomposition of the state characteristics are stored in this matrix. The number of features stored in F is limited by the application and the memory available in the sensor node. The singular vectors corresponding to these feature vectors are also stored and used to calculate a threshold ψ, as shown in Figure 2.

Observation phase

The observation phase is optional, but can be useful for learning certain anomalies or states and saving them in feature matrix F. This leads to the feature matrix F and the threshold value ψ being updated.

Implementation phase

In the implementation phase, new vibration values (X) are recorded and decomposed using SVD to obtain the feature vector f of the newly recorded signal. This feature is then analysed using CCA with the already learned feature matrix F of the good state. CCA attempts to analyse how different the learned features are compared to the newly recorded feature. The comparison scale is always 0 to 1, where 0 stands for very different and 1 for identical. The result of the CCA analysis is called the degradation coefficient. An example of a deteriorating bearing condition is shown in Figure 4.

Combination of singular value decomposition and correlation

This combination of feature extraction with SVD and subsequent correlation allows automated feature extraction and subsequent detection of changes in condition. Further details are described in the patent „Verfahren und Sensoranordnung zum Überwachen einer Funktion eines Bauteiles einer Maschine “, DE 10 2024 100 703 B3.[3]

www.imms.de/patent

3 *DE 10 2024 100 703 B3, https://register.dpma.de/DPMAregister/pat/register?AKZ=1020241007036*

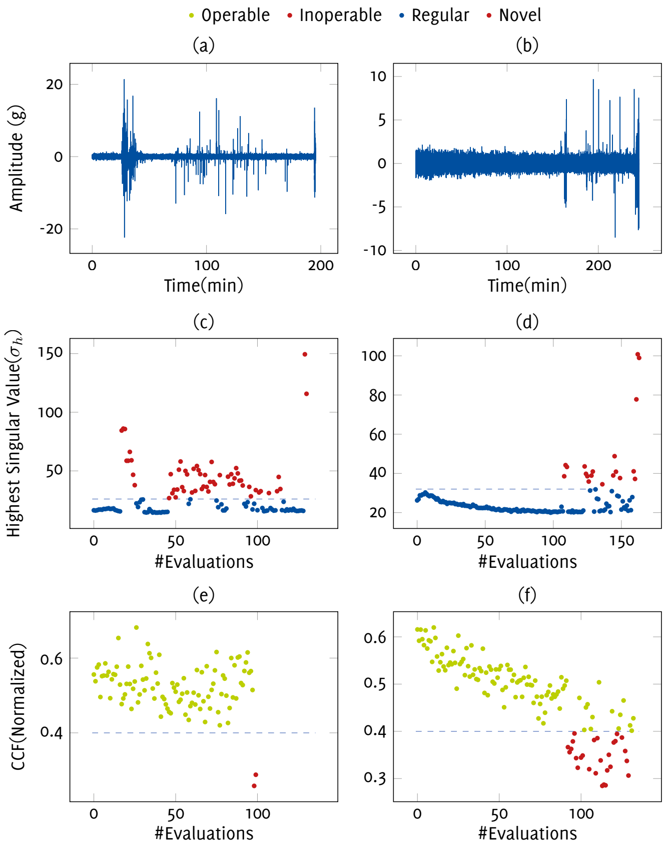


Figure 4:

Example of a deteriorating bearing condition. The columns show signals from two different bearings:

Top: vibration signals of the bearings

Centre: singular values of the vibration signals

Bottom: CCA of the singular values

Graphics: IMMS.

Anomaly detection with neural networks

Neural network methods have proven to be more efficient at recognising anomalies and distinguishing deviations from the normal state. When applied to unknown data, these methods are able to detect anomalies based on more complex patterns. As a result, this reduces the need to record known error states manually.

Two anomaly detection models were used during the research: LSTM-AD (Long Short-Term Memory Anomaly Detection) and w (Autoencoder Anomaly Detection). Both models were trained with vibration data that represent the normal state, i.e. fault-free, state of a machine. They learn the typical behaviour of the machine on the basis of a defined window size, i.e. a specific time period of the measurement data, and then predict the next set of measured values. This prediction is based on the patterns recognised during training.

To test the robustness of the models, the models were evaluated on various datasets, both with error-free data and with erroneous data. Since the models were only trained exclusively on data representing normal state of the machine, they are unable to accurately reconstruct the vibration data if an anomaly is present. This result leads to a "reconstruction error", defined as the difference between the actual and the predicted signal. An anomaly score is calculated from this error, which can indicate unusual or faulty behaviour. The data from all three vibration axes is first normalised and prepared for model training using a sliding window (moving window approach). The window size represents the input (X-train), while the subsequent time window serves as the target value (Y-train).

The reconstruction error resulting from the model is analysed using change point detection algorithm. This uses a window-based, stepwise approach to identify points in the signal at which the signal behaviour changes significantly, indicating potential anomalies. In a first step, the algorithm identifies possible breakpoints and calculates their error values. In the subsequent prediction step, it selects the optimal change points, taking into account the maximum number of permitted change points and applying a penalty score to discourage excessive segmentation. In this way, changes in the machine status can be recognised automatically and reliably.

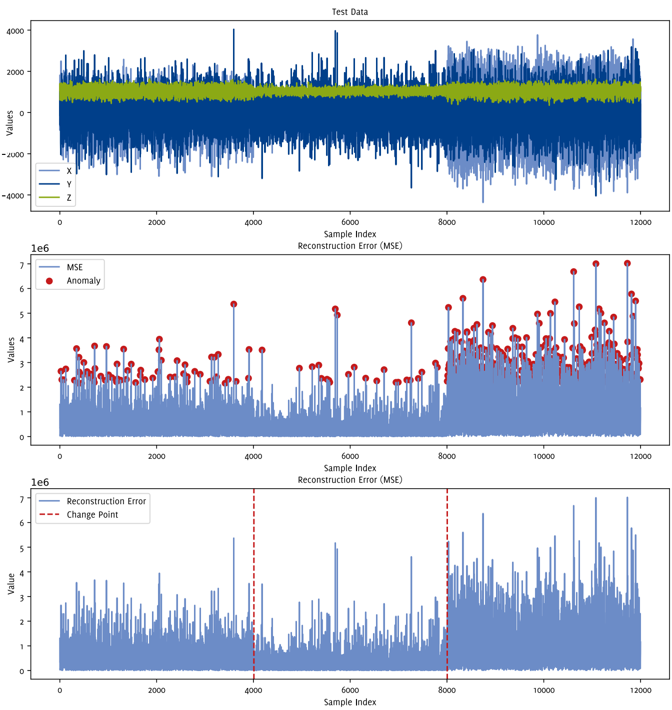


Figure 5:

Top: Test data

Centre: Reconstruction errors (anomalies with static threshold value),

Bottom: Reconstruction errors (change point detector).

Graphics: IMMS.

Figure 5 shows the vibration data, the reconstruction error with detected anomalies, once with a static threshold and a change point detection algorithm.

LSTM-AD (Long short-term memory anomaly detection)

The models analysed allow effective anomaly detection. LSTM-AD is particularly well-suited for analysing time-dependent data, as its feedback structure allows it to capture both long-term and short-term patterns in sequential signals. This makes it a powerful method when machine behaviour is strongly dependent on temporal sequences. However, the use of LSTM-AD requires a larger amount of training data and more complex model tuning making it more computationally intensive compared to other statistical approaches.

Autoencoder

In contrast, autoencoders offer a more efficient approach to anomaly detection, as it attempts to reconstruct input data as accurately as possible. If the reconstructed signal deviates significantly from the original, this may indicate an anomaly. Autoencoders are well-suited for stationary vibration data, i.e. data with relatively stable patterns over time that may change suddenly. This model is easier to train than an LSTM model, but is less suitable for strongly time-dependent behaviour and gradual changes in machine states.

Evaluation of the methods

All methods discussed can be used to recognise deviations from normal states in data. Singular value decomposition (SVD) is a robust method for dimension reduction and for identifying novel patterns in linear data. It is particularly suitable if the data structure is relatively simple and the anomalies represent minor deviations in the data structure. Anomaly detection algorithms are more flexible and powerful when analysing complex or non-linear systems. However, they can be more computationally intensive and require careful parametrisation.

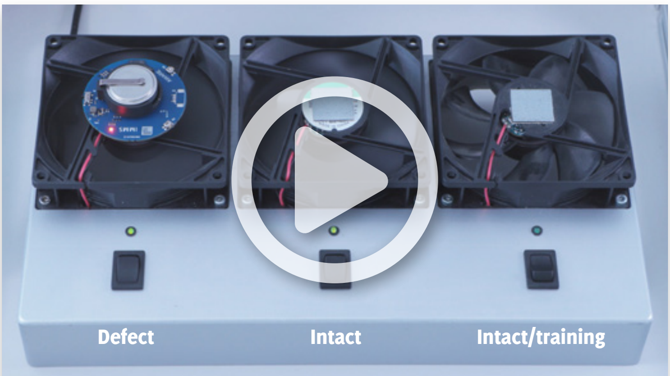
To illustrate a possible application in an industrial environment, algorithms for two scenarios were implemented in demonstrators.

The *k*-Means algorithm was implemented directly on a small, energy-autonomous sensor system as a local AI and evaluated with a demonstrator for fan monitoring as an example for monitoring bearings. A more complex and powerful anomaly detection was demonstrated in an energy-efficient edge AI system with local pre-processing on the sensor node and anomaly detection algorithms on the edge device with data processing based on the monitoring of vibrations on a shaker.

Fan demonstrator

A defective fan can be detected on the demonstrator using a small, energy-autonomous sensor system with local AI. Three fans were used, one had a damaged ball bearing, while the other two are intact. The battery-powered sensor node records vibration data, analyses it and classifies the current status. The system contains a vibration sensor that can detect vibrations up to 6.4 kHz and a microcontroller with an integrated radio transceiver.

The k-Means clustering algorithm was implemented on the sensor node. The sensor can be trained on the status of the intact fan. Another “intact” and a “defective” fan can then be recognised and classified accordingly without the data having been recorded beforehand. The result is displayed via a green or red LED, see Figure 6. The data can also be transmitted to an edge device via BLE (bluetooth low energy) with very low power consumption.



https://youtu.be/Yv-XzoZxICQ

Figure 6:

Fan demonstrator: The fans can be switched on and off individually. The sensor system is placed in the centre of one of the fans and is attached using a magnet. The status is indicated by an LED, green = intact, red = defective.

Photograph: IMMS.

Figure 7: Demonstrator system with: (1) vibration generator, (2) wireless sensor nodes, (3) edge device and (4) tablet. Photograph: IMMS.

Energy-efficient edge AI system

This demonstrator shows how vibration data can be recorded using a wireless sensor node and transmitted via BLE (Bluetooth Low Energy) to an edge device, where an LSTM-AD algorithm for anomaly detection is implemented.

Vibration data exhibits complex patterns that vary depending on the machine and process. Therefore, the required algorithms demand computational resources beyond what the sensor node can provide. However, the sensor node is capable of performing pre-processing on the vibration data. To increase energy efficiency and extend battery life, data compression techniques such as Singular Value Decomposition (SVD) are applied.

For this demonstrator, a vibration exciter (shaker) is used to generate vibrations similar to those found in industrial environments. The sensor node is mounted on the exciter system. The system is first used to train the model on a healthy (“good”) state. The sensor node records the vibration signal cyclically – configurable from once per second to once per hour – and transmits the data to the edge device, in this case a Raspberry Pi with no cloud connectivity. Deviations from the trained good state are detected on this device and visualised through a dashboard displayed in a browser on a tablet. If the generated vibration signal changes, these changes are detected and displayed graphically.

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

In its work on adaptive edge AI systems, IMMS is focussing on researching and implementing the determination and prediction of machine and tool states in the application field of predictive maintenance with the help of AI.

The results presented on unsupervised learning help to reduce the effort and costs involved in implementing AI for monitoring. The focus was on vibration sensors, as these are mostly used in practice to monitor machine states. Simple algorithms such as clustering were implemented on a microcontroller to show that they can be executed directly on ultra-low-power sensors. For more complex tasks, data must be transferred from the sensor node to an edge device on which the AI algorithms are executed. For this purpose, compression algorithms were analysed and implemented on the sensor node to send only the required data to the edge device and thus achieve the longest possible battery lifetime for the sensor node. It was shown that both the training and the inference, i.e. the AI-based classification, can be implemented directly on the sensor node or, in the case of more complicated algorithms, on edge devices such as a Raspberry Pi without any cloud access.

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On the basis of these solutions for monitoring machine states and automatically detecting deviations from good states, IMMS is endeavouring to advance further developments and is looking for application partners.

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Contact person: Dipl.-Ing. Sebastian Uziel, sebastian.uziel@imms.de

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The solutions presented were developed in the internal AI research group at IMMS, which is funded by the German Land of Thüringen, and in the HoLoDEC project.

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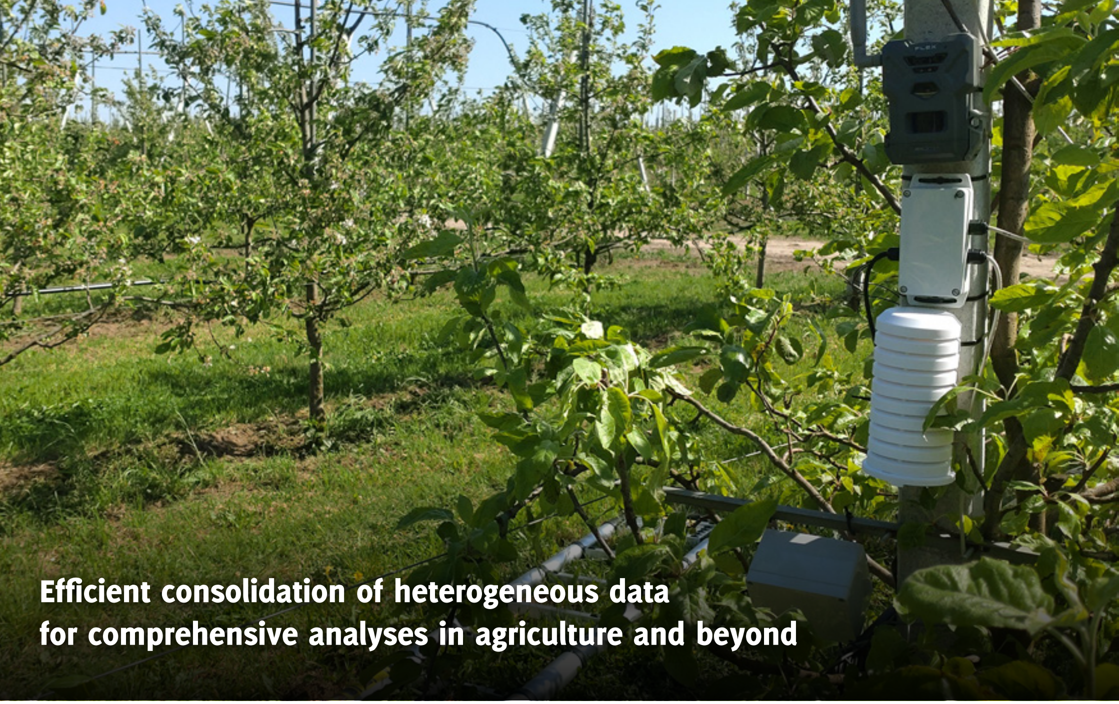
In 2024, the HoLoDEC project on which this report is based was funded by the German Federal Ministry of Education and Research (BMBF) under the reference 16ME0703. The author is responsible for the content of this publication.



Efficient consolidation of heterogeneous data for comprehensive analyses in agriculture and beyond

In MIRO, data is collected in the form of time series and used, among other things, for research on the digital twin of regional fruit varieties. IMMS has developed a concept for the efficient merging of heterogeneous data for comprehensive analyses in agriculture, which can also be used for other applications. Photograph: IMMS.

Motivation and overview

In the "Mitteldeutsche Innovationsregion Obstbau" ("Central German Innovation Region for Orcharding", MIRO) project, IMMS is working on digitalisation solutions with the aim of strengthening the future security of the entire fruit value chain from cultivation and processing to marketing in the region of Central Germany and thus addressing issues such as a rapidly changing climate and a challenging skilled labour and competitive situation in the agricultural economy, especially in fruit growing. For example, problems in processing could be avoided by adapting cultivation methods or finding locally suitable fruit varieties depending on the specific environmental and soil conditions, even in times of climate change.

www.imms.de/miro

The exchange and consolidation of data from different systems and actors is central to digitalisation. For example, as in many other disciplines, a wide variety of data is required in agriculture to ensure efficient processes on and across farms along the value chain. This ranges from producers and suppliers to logistics with refrigerated warehouses and processors such as wineries or canning manufacturers to finished

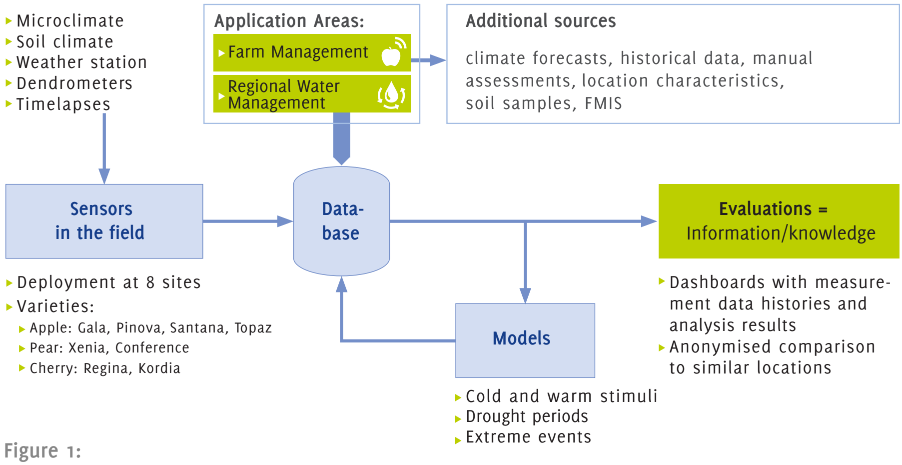


Figure 1:
Data requirements and processing for the digital twin in MIRO (schematic). Graphic: IMMS.

products such as juice, wine or apple sauce for end customers in retail. However, other interest groups such as plant breeders, tree nurseries or authorities also increasingly expect data to be exchanged with the farms. This is made more difficult by numerous different systems, unsuitable interfaces (e.g. manufacturer-specific) and separate initiatives. As a result, data has to be processed multiple times, sometimes with increased manual effort if things have to be documented or data from different systems have to be exported and merged manually. Such activities are not among the core tasks of farmers.

Against this background, IMMS has worked on two use cases in MIRO: the data exchange between the players in the region just briefly outlined and a digital twin for feedback on variety characteristics at different locations, along the value chain.

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IMMS has analysed the data exchange use case with regard to both agricultural aspects in general and the project partners involved. First of all, the needs of both target groups were analysed and the efficient, ideally automated merging of data and its storage in a form suitable for further use for various purposes were identified as objectives.

The solution approach based on currently available platforms should implement a standardised, central repository for all types of structured and unstructured data, which facilitates the retrieval and storage of data as well as subsequent retrieval or analysis using data from multiple data. This approach should also not be specifically limited to the processing of data in MIRO, but rather also benefit other data-intensive applications, e.g. in AI applications.

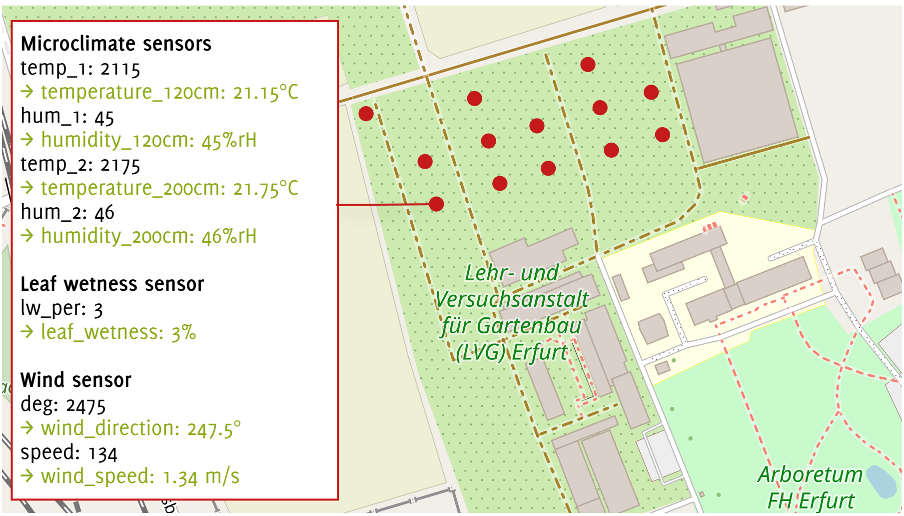
Data collection of time series using the example of digital twins of regional fruit varieties

At IMMS, extensive data is collected not only in MIRO, but also in other projects, such as EXPRESS, specifically time series data from various types of sensors in agricultural fields, weather data and image data. Data sources are sensor installations operated by IMMS (such as wireless sensor networks, weather stations or wildlife cameras for plant observation), partners or also public and commercial data providers on the Internet, such as Deutscher Wetterdienst (DWD, German weather service) or sensor platforms from which data can be obtained via various interfaces (APIs).

www.imms.de/express

Although time series data in these projects are already systematically entered into time series databases at the institute, they are written by gateways in the field without further processing. Aspects such as the assignment of measuring nodes to measuring points (which may vary over time) or the assignment of index-referenced sensors to specific measuring depths or heights can only be associated with the data in subsequent steps. In practical terms, this means that this meta-information

Figure 2:
Raw vs. semantically processed data for a sensor node. The processing includes the assignment of semantic references such as installation height/depth and conversions. Map created with MapOSMatic/OCitysMap on 21 July 2025. Map styles: Baumkarte by Oliver Rudzick; Allotments overlay; Data source: Map data ©2025 OpenStreetMap.org and contributors (see http://osm.org/copyright).



must be recombined with the data for any further use, which is prone to errors if not done automatically. Furthermore, time series databases, especially InfluxDB, frequently used at IMMS, typically cannot be queried using the standard SQL database query language, which makes it difficult to use for analyses.

The work in MIRO on the digital twin use case requires a more extensive evaluation of data and has shown the necessary starting points for the company's own databases. Here, sensor-based and manually collected data, such as that from manual assessments, should allow conclusions to be drawn about the suitability of varieties against the background of climate change. On the other hand, other projects dealing with entirely different research topics but also with the aggregation and evaluation of large amounts of data have equally shown a need for and the potential of new approaches.

Modern approaches for large, heterogeneous databases

Work in the MIRO use case of data exchange therefore began by analysing the state of the art for data storage in general. Conceptually, after the older concepts of data warehouses for the efficient storage of standardised, structured data and data lakes for the efficient storage of heterogeneous (including unstructured) data, the state of the art has arrived at the so-called (data) lakehouse, which strives to combine the advantages of both approaches.

There are various open source solutions for lakehouses that are complex to set up and use and rely on object stores as data storage. An object store saves files as objects in so-called buckets. In these object collections, they are stored by name, an optional path and possibly other attributes. Examples of object stores are cloud storage services such as Amazon AWS S3 or the open source solution MinIO with a compatible interface. Prominent lakehouse solutions in the open source space are Apache Iceberg or Apache Hudi, or, commercially, Databricks or Snowflake. Iceberg and Hudi were analysed in more detail as they can also be operated on-premise.

When looking at full-blown lakehouse solutions, it quickly became clear that they require powerful hardware for operation on company infrastructure, such as clusters for Spark SQL as the query engine. On the other hand, they also require considerable expertise for operation and use. The latter represents a significant hurdle for an in-

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stitute or other operator in terms of IT resources and training of specialists without in-depth database knowledge. However, some aspects of the complex lakehouse solutions are motivated by big data applications and Fortune 500 companies, as it is the backend for the entirety of their corporate data and thus business. In contrast, this exceeds the requirements for the storage of measurement data and analyses (WORM, write-once read-many) by a significant margin.

Looking at current technologies and alternative approaches has led us to a viable alternate approach that realises a lakehouse by storing Apache Parquet files directly in a suitable hierarchical file system structure in the object store. Parquet is a binary file format for tabular data that is now being widely used. In contrast to CSV, Parquet files are much more efficient in terms of storage space and read performance and also avoid typical problems when working with CSV files (such as unclear data types of columns, handling of missing values, etc.). Furthermore, they allow for the integration of metadata. Parquet files in MinIO/S3 can be queried via Apache Spark SQL or via the in-process database DuckDB via SQL, much the same as regular databases. This approach avoids the complexities of full-blown lakehouse table formats in use and operation; restrictions compared to these are insignificant for the utilisation scenarios under consideration.

Goodbye CSV, hello Parquet – More flexible yet lightweight data storage for MIRO

Instead of writing data from the source, especially sensor installations in the field, directly to the lakehouse, it has advantages to retain a time series database such as the InfluxDB already being used in these projects. This is easier and more lightweight to access from resource-constrained devices in the field such as IoT gateways and can also be located somewhere other than centrally on a server at IMMS, if required. The flexibility of InfluxDB compared to SQL databases has proven itself in that no rigid schema needs to be defined and maintained. And since it does not make sense to maintain all the other information necessary for data transformation and metadata augmentation on the gateway, this step is better realised downstream and separately.

The ingress into the lakehouse is carried out periodically using a set of flexible custom tools. The data is processed (filtered, converted) and enriched with metadata (physical quantities, units, locations etc.). This process results in Parquet files pertaining to individual sensor installations and specific time ranges, which are stored in a well-thought-out organisational structure in MinIO. Data can then be retrieved from them and processed further.

Data storage using InfluxDB or other databases

Figure 3 shows an overview of the concept with two tiers of data storage: The first tier in this case consists of an InfluxDB instance (own preference: other databases would also be conceivable here if the approach was to be adopted by others) for sensor data collection and other existing or externally-provided sources, e.g. other databases or simply CSV files. A set of dedicated tools is used to "lift" data from this first tier into the lakehouse. This involves some initial processing and metadata annotation. The lakehouse can be used for further processing, visualisation and as a basis for interfaces or data exports, as is planned for the digital twin of regional fruit varieties.

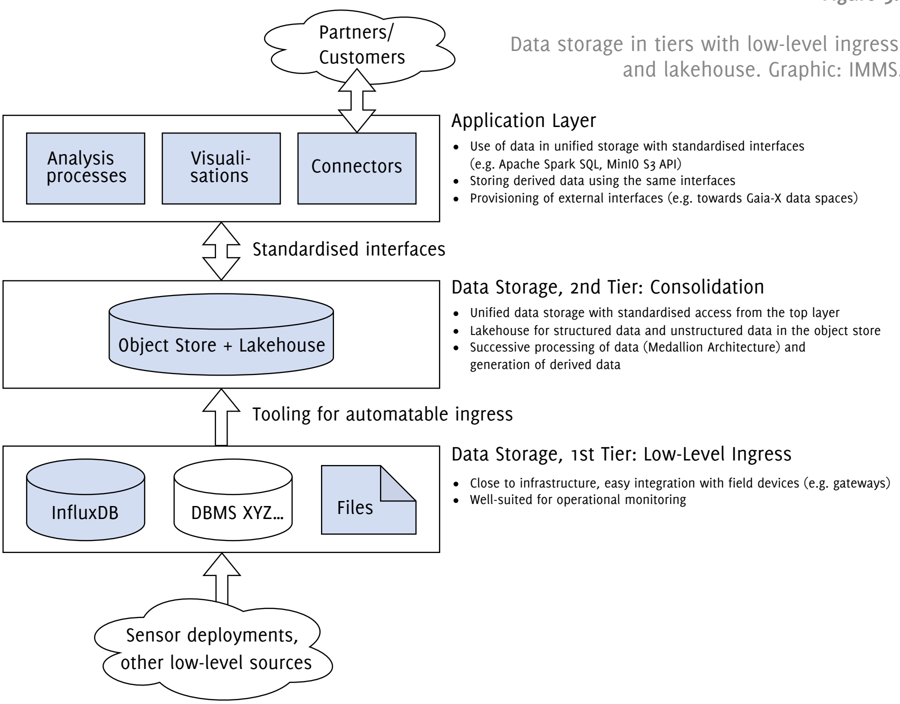

Figure 3:

Data storage in tiers with low-level ingress and lakehouse. Graphic: IMMS.

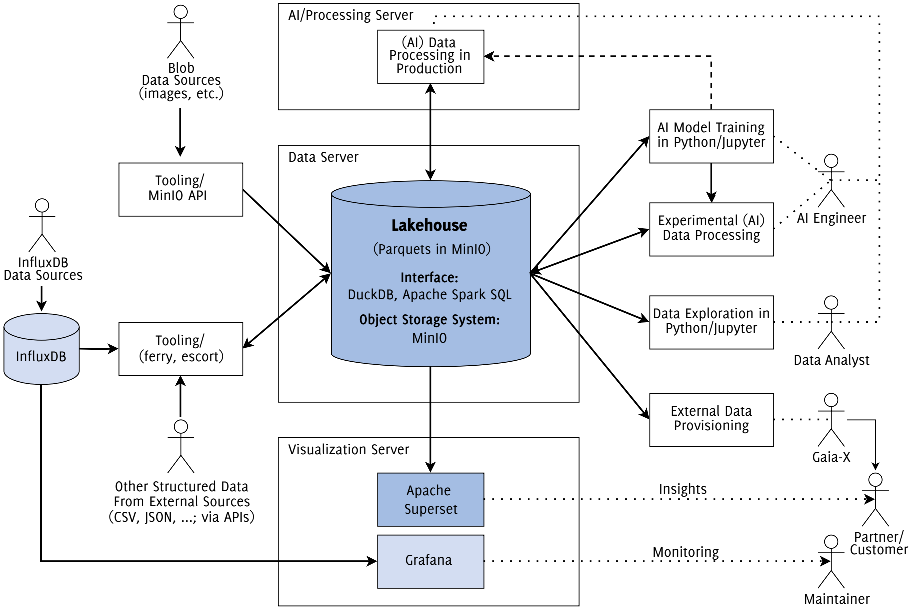

Figure 4: Sustainable data storage via a lakehouse based on Parquets in MinIO. Graphic: IMMS.

Figure 4 further details the concept: At the heart of the data storage is the lakehouse based on Parquet files in a MinIO object store. In the MinIO/lakehouse, there are individual buckets for each project or sensor deployment. In each of these buckets, there are two directories at the top level: “warehouse” for structured data, further organised according to the levels of the so-called Medallion Architecture – with levels Bronze, Silver and Gold for different degrees of processing – and “blobs” for differently or unstructured data such as images, videos or AI models.

Automatic and continuous data transfer

The ingress, i.e. the transfer of structured data into the lakehouse from InfluxDB instances and other sources, is automated and continuous using two software components implemented for this purpose. These are flexibly configurable and generate time slice Parquets (each for one year, one month, one day or one hour). By writing data in individual files for shorter time periods and merging them into larger time periods as soon as those are over, inefficient constant rewriting of all available data is avoided. When the Parquets are created, they are enriched with metadata based on a JSON structure conceived by us. For each time series, the metadata is also stored in a separate JSON file with a related name that can be accessed even more easily.

Figure 5: Monitoring dashboard, here for the commissioning of a Mira sensor network, based on Grafana and raw data including technical metadata in InfluxDB. Source: IMMS.

InfluxDB remains the preferred source for monitoring sensor installations as it is easier to understand problems at the level of raw data and other technical metadata, which are, on the other hand, not relevant for the actual data analysis and therefore not transferred into the lakehouse. Here, Grafana has proven itself for plotting data in dashboards. In future, Apache Superset will be used as the primary means of visualising processed data in the lakehouse. In contrast to Grafana, Superset can also visualise data other than time series and individual values and offers interaction options.

Data processing

Data processing on the lakehouse can be carried out using various approaches: Python and R make it equally easy to access Parquets in the lakehouse via DuckDB or Spark SQL. This applies to algorithmic processing approaches as well as AI-based ones. When developing processing algorithms, it is also easy to initially work with fixed exemplary Parquets and then switch to “live data” in the lakehouse by adjusting the path or URL during production, without having to make any adjustments to the code. Processing results can also easily be stored as Parquets in the lakehouse, but can also be written and validated locally during development for cross-checking.

In MIRO, a MinIO production instance has been set up on servers at IMMS. The setup of an Apache Spark SQL cluster was dispensed with in favour of using DuckDB to query Parquet files. In addition to the MinIO instance, productive instances of the tools created for automated data ingress have been configured and are running in production.

On this basis, all time series data previously and still being stored in InfluxDB instances for the digital twin in MIRO could be fed into an automated continuous ingress into the lakehouse, which preprocesses the data, semantically assigns it and annotates it with metadata. Further automation also continuously performs interval normalisations of the data typically recorded asynchronously, and also script-based processing using Python and R. This means that data from all sensor installations is continuously being preprocessed and made available in the lakehouse with low la-

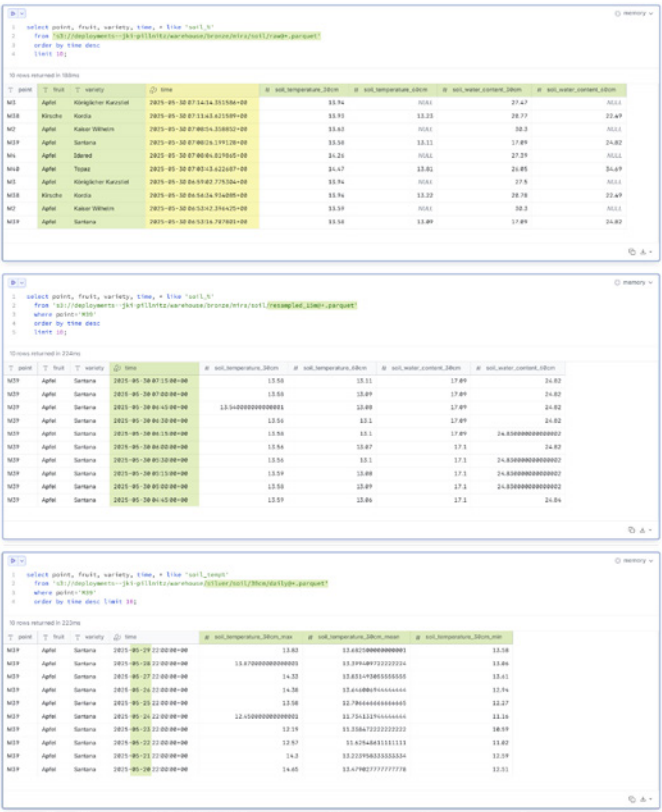

Figure 6:

Illustration of data preparation using sample data from SQL queries on the lakehouse via DuckDB.

From top to bottom:

1. Raw data from different measurement points written on Bronze, with non-uniform/asynchronous timestamps and metadata annotation.

2. Interval-normalised data of a measuring point written on Bronze.

3. Daily aggregates for a measuring point on Silver. The URLs in the queries also show the organisational structure used in the lakehouse/MinIO.

Graphic: IMMS.

tency. The data generated at the Medallion Architecture's Bronze level is periodically further processed into Silver (e.g. through aggregations). In addition to structured data, unstructured data, such as images or even firmware images as backups, are also stored in the lakehouse, where it is centrally accessible.

In MIRO, image data is also stored in the lakehouse, which can be easily accessed with MinIO/S3 client libraries and thus be incorporated in data processing. The intermediate results obtained from working with the data in the form of derived data can in turn be stored in the warehouse part of the lakehouse.

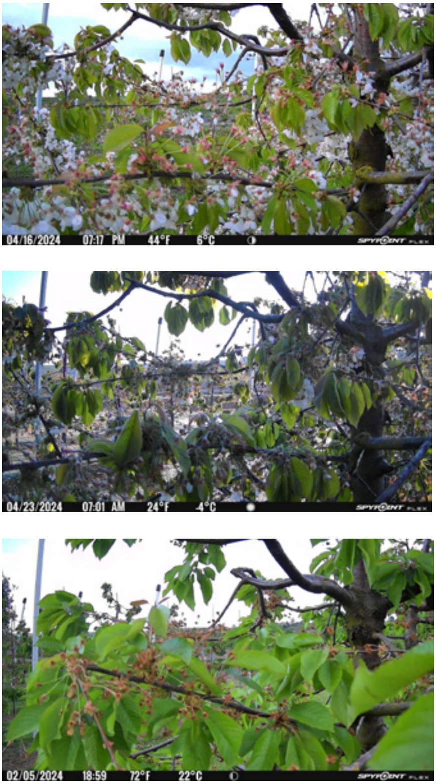

Figure 7: Frost damage to cherry blossoms at LVG Erfurt, documented by wildlife camera photos in April 2024: blossoms before frost, during frost, after frost. Photographs: IMMS.

In addition to data collected by us, various data from external services are also integrated and stored as Parquet files. In particular, data from the DWD, the Helmholtz Centre for Environmental Research (UFZ), but also data from various weather station providers are integrated, depending on which sensor technology was already installed at the respective partners' or synergistically deployed by partners in the project.

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An initial site analysis has already been carried out with the aim of visualising the effects of climate change. In doing so, data on historical climatic development provided by the DWD, climate projections provided by project partner UFZ and automated aggregations of monthly temperature and precipitation data were used. Figure 8 shows an exemplary analysis in Superset.

Temperature (monthly average)

Metric	Average temperature [°C]												
month / slice	1	2	3	4	5	6	7	8	9	10	11	12	Total (Average)
200x	1.8	2.0	4.4	8.5	12.4	16.0	18.3	18.0	13.6	9.3	4.1	2.2	9.2
201x	1.9	3.2	5.2	8.5	12.8	15.8	18.1	18.1	14.4	9.3	4.4	2.0	9.5
202x	2.7	2.8	5.5	8.8	13.3	16.0	18.1	18.2	14.0	9.6	4.6	2.5	9.7
203x	2.4	3.1	5.8	9.0	13.1	16.3	18.6	18.4	14.5	10.0	4.8	3.0	9.9
204x	2.7	3.5	5.1	9.2	13.8	16.8	19.2	19.3	14.8	10.0	4.7	3.0	10.2
205x	2.7	3.6	5.8	9.5	13.3	16.7	19.1	18.9	14.4	10.3	5.2	2.7	10.2
206x	3.2	3.4	6.2	9.5	13.9	17.3	19.9	19.3	15.1	10.7	5.4	3.4	10.6
207x	3.0	3.9	6.0	9.6	14.5	16.7	19.6	19.5	15.3	10.9	5.9	3.6	10.7
208x	3.0	3.5	5.8	10.1	14.4	17.5	19.6	19.0	15.2	10.5	5.5	3.5	10.7
209x	3.1	3.9	6.1	9.7	14.3	17.3	20.0	19.9	16.0	10.9	6.1	3.6	10.9
Total (Average)	2.7	3.3	5.6	9.3	13.6	16.6	19.1	18.9	14.7	10.1	5.1	2.9	10.2

Precipitation (monthly sums average)

Metric	Average precipitation sum [mm]												
month / slice	1	2	3	4	5	6	7	8	9	10	11	12	Total (Average)
200x	32.1	38.9	44.9	43.9	62.8	53.9	67.5	57.3	48.8	35.6	50.6	50.7	48.9
201x	43.2	38.4	49.0	44.5	55.1	49.3	72.4	56.3	55.6	38.7	64.9	52.8	51.7
202x	39.6	40.1	49.7	41.9	58.6	54.5	84.5	52.8	52.1	40.0	60.1	53.7	52.3
203x	42.3	39.4	45.9	41.0	58.7	53.5	78.6	50.5	59.5	39.1	57.9	61.2	52.3
204x	40.7	41.8	49.8	40.8	55.4	54.7	67.5	55.5	54.0	37.9	61.2	61.5	51.7
205x	46.1	41.7	49.3	41.4	52.5	50.6	77.4	46.1	54.2	47.0	61.6	51.1	51.6
206x	46.6	39.4	42.2	48.5	53.2	54.1	72.2	52.7	51.6	37.1	63.2	56.7	51.5
207x	50.9	37.1	53.7	40.8	57.9	58.4	76.1	53.0	57.6	43.4	63.8	58.1	54.2
208x	45.0	41.7	51.0	40.5	61.5	50.2	78.3	58.7	56.4	36.6	57.0	59.7	53.0
209x	44.3	43.9	55.5	41.7	58.9	55.5	74.5	45.7	45.2	39.3	63.6	60.4	52.4
Total (Average)	43.1	40.2	49.1	42.5	57.5	53.5	74.9	52.9	53.5	39.5	60.4	56.6	52.0

Figure 8:

Forecasts for annual temperature and precipitation for the LVG Erfurt site using the model RCP4.5 with a global warming of 2.6 K by 2100.

Data: UFZ, visualisation: IMMS via Apache Superset.

Outlook in MIRO

In MIRO, a data management concept was developed as a basis for data collection and analyses, which can be used in future to derive well-founded decisions for the cultivation of locally suitable fruit varieties that can cope with climate change, based on climate and soil conditions, among other things.

Based on the Silver data currently available, further evaluations beyond the current site comparison are to be added in the future. To this end, further assessment data is to be automatically written to the Lakehouse, thus enabling images to be analysed (e.g. to verify identified flowering times) and make it possible to correlate yield data. Further sensor systems are also planned to support farms in recording data and to automate the acquisition of additional data as much as possible. The architecture presented enables customised, automated data exchange, even between different actors, through targeted configurations of ingresses and export mechanisms if the corresponding interfaces are known.

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The presented lakehouse architecture is not limited to the context of MIRO. By standardising the approach presented, data retrieval and storage can be easily implemented using generic, reusable libraries for common analysis tools and languages (e.g. Python, R). As an S3-compatible object store, MinIO also allows the same tools and libraries to be used for other S3-compatible object stores, meaning that the solution can also be used with cloud storage, for example, without the need for any other adjustments.

Contact persons:
Dipl.-Inf. Marco Götze, marco.goetze@imms.de
Dr.-Ing. Silvia Krug, silvia.krug@imms.de

With support from
Federal Ministry of Food and Agriculture
by decision of the German Bundestag

Project manager
Federal Office for Agriculture and Food

In 2024, the MIRO project was supported by funds of the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany. The Federal Office for Agriculture and Food (BLE) provided coordinating support for future farms and future regions as funding organisation, grant number 2822ZR0005.

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RESEARCH FIELD

MAGNETIC 6D DIRECT DRIVES WITH NANOMETRE PRECISION

https://youtu.be/XiQR5vMODg4

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.

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Highlights of 2024 in our research on magnetic 6D direct drives with nanometre precision

Reconstruction and expansion of the mechatronics laboratories

In 2024, tonnes of drives were moved at IMMS for the redesign and expansion of the mechatronics laboratories to provide more space for research into sub-nanometre precision drives at IMMS. The fundaments in the high-precision laboratories, which were previously decoupled with steel springs, have now been equipped with pneumatic vibration isolators so that the drives can work largely isolated from building vibrations. In addition, more space has been created, including a new laboratory for carrying out a wide range of research projects that do not require the high demands of vibration isolation and environmental control as in the high-precision laboratories.

Das Video zeigt einen Teil der Umbauarbeiten in den Hochpräzisionslaboren: https://youtu.be/XiQR5vMODg4

Thanks to the increased capacity in the high-precision laboratories, the "small" 3D nanopositioning system could finally be moved to suitable foundations and expanded into the new NPS6D100 system, which is now setting new standards in positioning performance. In the newly equipped high-precision laboratories, work was already carried out in 2024 in the internal NextGenPos research group, in the GraKo NanoFab research training group and in the OptoMed vacuum air bearing project, preparations were made for the VirtuSen research group, which is set to start work in 2025, and commissioning, characterisation, analysis and optimisation for high-precision industrial services were made.

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At the same time, a multi-coordinate direct drive was retired after 15 years and moved from the laboratory to the foyer – as a showpiece and discussion starter for various types of visits. In the remodelled laboratories, research is being carried out into accuracies down to the picometre range and the transfer to industrial applications is being further advanced.

Test setup for investigating suction power losses in the molecular flow range depending on the hose geometry. Based on these and other preliminary investigations, the OptoMed vacuum air bearings project is determining the influence of the suction pipes to minimise the residual gas inflow of air bearings for high vacuum applications. Photograph: IMMS.

Project start: OptoMed vacuum air bearings* for high-precision vacuum applications

With ever smaller structure sizes on microelectronic chips, the demands on manufacturing accuracy in the semiconductor industry are growing.

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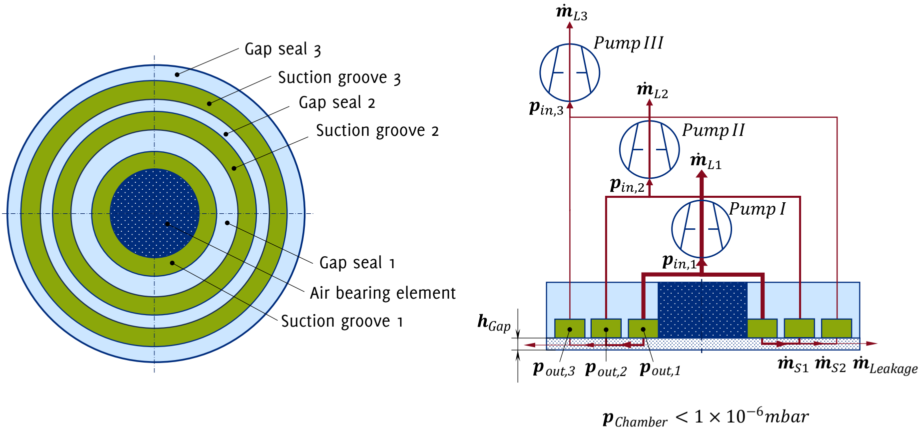
Positioning systems that have the highest precision over large motion ranges according to the current state of the art are air-bearing direct drive systems. Their moving part floats on a thin cushion of air. The stationary and sliding parts of the drive therefore do not touch each other, resulting in virtually friction-free movement. This enables positioning accuracies in the single-digit nanometre range, i.e. down to millionths of a millimetre.

At the same time, maximum particle-free purity is required in semiconductor production. This is why large parts of manufacturing are transferred to a vacuum. However, not all vacuums are the same. In the targeted high vacuum, the proportion of residual gas particles is less than a billionth of that under atmosphere.



Schematic representation of a planar air bearing suitable for high vacuum with cascades of suction grooves arranged concentrically around the bearing element. Graphic: IMMS.

So how can a system that relies on a continuous air supply function in such an airless environment? The answer seems simple. The air must be continuously extracted before it reaches the surrounding vacuum. This is made possible by suction grooves that surround the air bearing element and are connected to vacuum pumps.

The challenge is to find suction pipes (see illustration) that are large enough to remove enough air and at the same time generate so few disruptive forces that the advantages of air bearings are not eliminated. In addition, many materials cannot be used in a high vacuum due to their material composition and the associated outgassing.

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The project is therefore developing solutions for vacuum-compatible air bearings and demonstrating their function using a prototype drive system.

One of the first steps was to set up a test setup with which suction power losses can be determined, particularly in the molecular flow range, depending on the pipe geometry. This is necessary for reliable dimensioning of the bearing system and helps in the selection of suitable suction lines. The test bench offers the possibility of allowing the smallest quantities of gas flow of up to around 3×10^{-5} mbar l/s to flow into a pipe system in a defined manner and to determine the pressure difference between the beginning and end of the pipe using measurement technology.

Funded by
DFG Deutsche Forschungsgemeinschaft
German Research Foundation

Alex S. Huaman with IMMS team after the successful defence of his dissertation.

Photograph: IMMS.

Dissertation on a robust adaptive control approach for highly dynamic nanopositioning defended

On September 17, 2024, Alex S. Huaman, specialist for control systems at IMMS, successfully defended his dissertation "Highly Dynamic Nanopositioning: A Robust Adaptive Control Approach" at Technische Universität Ilmenau. He created his work at IMMS in the NanoFab research training group 2182 where he and 13 other doctoral students from Ilmenau TU are working on solutions for tip- and laser-based 3D nanofabrication in extended macroscopic workspaces. They are being supervised by professors and scientific staff of Ilmenau TU and IMMS. The control strategy developed by Alex S. Huaman offers both high-precision and rapid disturbance rejection. Experiments with a nanopositioning system showed that this control concept maintains positioning errors within the single-digit nanometre range, even during complex motion tasks. These concepts may significantly benefit future technologies in fields that require ultra-precise movement across relatively large volumes such as semiconductor industry, biotechnology, and quantum research.

www.imms.de/nmdrives

www.imms.de/nanofab

Need for nanopositioning

Nanopositioning is crucial for fabricating miniature devices, analysing biological samples, or building quantum systems. As researchers and industries push toward ever smaller scales, they require machines that not only move with extreme precision but also offer a larger working range than traditional nanopositioning stages (e.g., piezo-based systems).

Control challenges of the latest nanopositioning system by IMMS

To address this need, a novel system called the NPS6D200 has been developed. It is a long-range nanopositioning platform capable of moving in six degrees of freedom, i.e., translation along the x, y, and z axes (forward – backward, left – right, up – down), and slight rotation about each of those axes. Despite offering a large motion range, Ø 200 mm in horizontal directions and 25 mm vertically, it maintains exceptionally high positioning precision. The moving part, called the slider, is guided without contact using air bearings and is driven by coils and magnets without mechanical friction. The machine includes laser-based sensors to measure its position within the nanometre level. These features facilitate machine operation, as the NPS6D200 avoids common problems such as mechanical friction.

Control strategy

Controlling such a versatile system poses a significant challenge, not only in terms of high-precision performance but also in also active disturbances rejection. To address these issues, an advanced motion control method has been designed using two layers. The first is a feedforward controller, which provides the desired motion of the machine and sets the required forces accordingly. The second is a feedback controller, which continuously compensates for errors by comparing the actual position with the desired reference.

Likewise, the feedback controller integrates two control algorithms. The primary controller follows a standard method known as Active Disturbance Rejection Control (ADRC). It estimates disturbances such as cross-couplings between axes and actively compensates for them. However, ADRC alone cannot deal with changes in system parameters that happen over time or against unexpected errors. For this reason, a second control law was introduced, i.e., an adaptive augmentation. This controller can predict and adjust itself during operation. It observes the measured positions and rapidly adapts its internal control rules to maintain high performance, even when the machine parameters change. Mathematical analysis and simulations ensure that the nanopositioner remains stable and delivers smooth motion, even during demanding tasks.

By combining these approaches, the system not only maintains high precision but also enhances robustness. In fact, it can handle uncertainties and disturbances more effectively than conventional control strategies.

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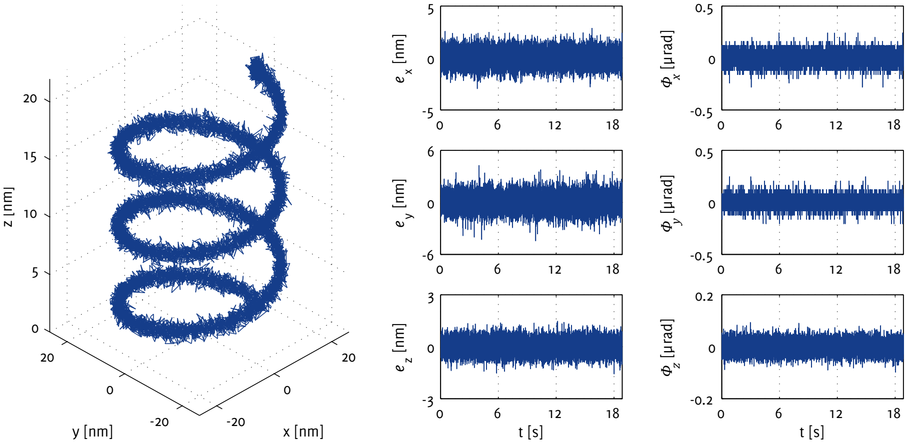

Helix motion with Ø40 nm x 20 nm. Plot of the 3D helix (left side), time series of the servo errors (e_x, e_y, e_z) and rotations (ϕ_x, ϕ_y, ϕ_z) during motion (right side). Graphics: IMMS.

Validation of the control concept and outlook

Experiments with the NPS6D200 show that this control concept maintains positioning errors within the single-digit nanometre range, even during complex motion tasks. For instance, the system can follow complex paths ranging from a few nanometres to several millimetres with highest precision. Figure 1 illustrates the system's performance during a synchronous 3D motion and shows the stability of the tracking errors with deviations below 5 nanometres.

Finally, the investigations report a technically sophisticated yet practically viable solution for nanopositioning control. The application of the proposed control strategy, especially the addition of adaptive feedback, offers both high-precision and rapid disturbance rejection. This development may significantly benefit future technologies in fields that require ultra-precise movement across relatively large volumes.

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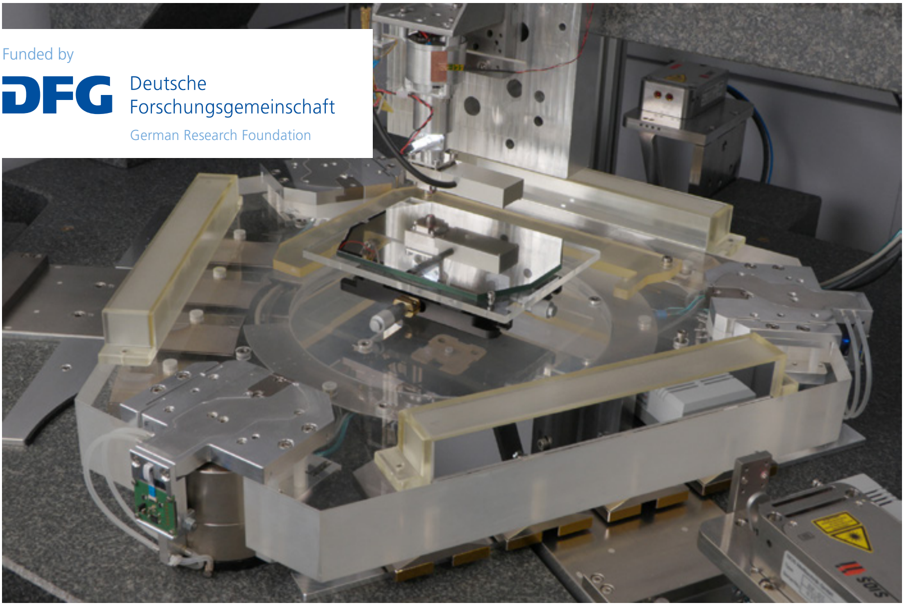

The patented control concept with extended dynamic observer enables highly effective compensation of disturbance variables for highly dynamic multi-coordinate direct drive systems such as this one. It significantly increases drive precision in dynamic operation. Photograph: IMMS.

iENA silver medal for observers of atoms: New control concept for sub-nanometre-precise positioning

The IMMS patent “Positioning system with a controller and method for its configuration” was honoured with a silver medal at the Thuringian award ceremony of the PATON | Landespatentzentrum Thüringen at Technische Universität Ilmenau on 12 December 2024 in the competition of the iENA inventors’ fair. PATON had represented the inventor Alex Huaman in the competition at the iENA in Nürnberg at the end of October.

www.imms.de/awards

Why you need to be more precise than nanometres

Technical products such as smartphones and medical devices are becoming increasingly miniaturised. The need for precision machines to measure and process the smallest structures and objects with high accuracy is therefore growing in many industrial sectors. These machines can not only position objects with nanometre precision and even greater accuracy in the shortest possible time. They can also do this in comparatively large working areas of several hundred millimetres. Translated into other dimensions, you could get into a rocket in Peru, enter the target coordinates of the car park at IMMS, fly off and quickly and safely hit the targeted parking space, as long as it is only 60 cm wider than the rocket.

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Innovative control concept for highly dynamic multi-coordinate direct drive systems

Highly dynamic multi-coordinate direct drive systems, such as those developed at IMMS, enable such precise work. These systems are operated in a closed control loop. For this purpose, a complex control algorithm calculates new target values for the drives from measurement data on the actual state of the positioning slide.

The newly developed control concept with extended dynamic observer enables very effective compensation of disturbance variables. It therefore significantly increases drive precision in dynamic operation.

With this new approach, disturbance forces do not have to be measured precisely to be compensated. In addition, the control system adaptively adjusts to long-term changes in the disturbances.

New disturbance estimator enables compensation of disturbances

The new control concept was developed for a nanometre-precise drive system with three drive and guide elements. Similar to a tripod, these elements generate vertical movements and tilts around the horizontal spatial axes. In addition to the aerostatic guide, each of these three elements contains two parallel actuators that generate and transmit a vertical force to the moving part. These interlinked individual axes are each implemented with individual axis controllers with the aforementioned properties, which reduces the complexity of the system.

The new feature of the control concept is the disturbance estimator, which assesses the forces and torques disturbing the system in real time. This estimation is based on specially designed models and measurements taken shortly before the effective actuation. These estimated disturbances can be used by the controller to compensate for the actual disturbing forces. This helps to counteract crosstalk between the axes and errors, as well as interference from the environment and from within the system.

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German patent: DE 10 2023 118 056 B3, IP available, Patent applicant/owner: IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH (IMMS GmbH), Inventor: Alex S. Huaman.

www.imms.de/patent

IMMS at Precision Fair

Representatives of the mechatronics team at Precision Fair 2024.

IMMS was represented at the Thuringian joint booth at the Precision Fair 2024, the leading trade fair for high and ultra-precision technology in 's-Hertogenbosch in the Netherlands. Devices such as smartphones and medical devices are becoming ever more powerful and require increasingly smaller and more precise measurement, production and construction processes. Such highly complex technology can only be implemented through close cooperation. The trade fair is a platform that spans disciplines, companies, educational institutions and national borders and contributes to the constant expansion of technological boundaries through the international exchange of knowledge. IMMS presented demonstrators at the trade fair stand and contributed three presentations to the accompanying euspen Special Interest Conference “Precision Motion Systems & Control”. These dealt with the investigation of air bearing vibrations using a 3D nanopositioning system, the suppression of interference in periodic movements with large proportions of constant speed using a tilting mirror test setup, and the implementation and achievable performance of combined pneumatic-electromagnetic actuated vertical drives in the NPS6D200 nanopositioning system.

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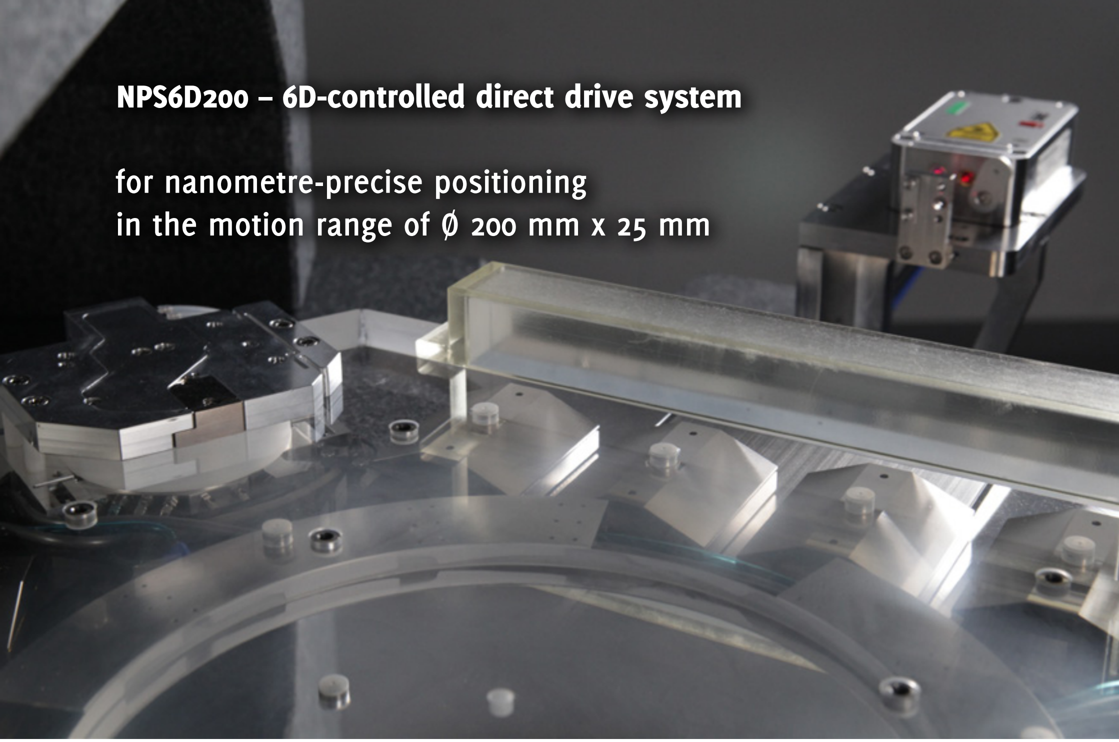
https://youtu.be/r3PKo82sfvs

One of the developments presented at the Precision Fair – the NPS6D200 6D nanometre planar positioning system for high-precision positioning with a large range of motion.

Source: IMMS.

NPS6D200 – 6D-controlled direct drive system

for nanometre-precise positioning in the motion range of Ø 200 mm x 25 mm



6D-controlled nanopositioning system NPS6D200 developed at IMMS: The close-up shows the slider with one of the three lifting modules for vertical movements up to 25 mm, magnetic bridges and a laser interferometer. Important milestones for this system were developed in the internal research group NextGenPos and in the DFG research training group NanoFab. Photograph: IMMS.

Motivation and overview

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Nanotechnology has not only been on the rise in recent years. In the meantime, cutting-edge research in the nanosciences has advanced into the sub-nanometre range. It is not only the semiconductor industry, but also a growing number of new applications, e.g. in nano-optics, photonics or biosensor technology, that require measurement and fabrication techniques that offer a resolution and precision of less than 10 nm. In addition to the further development of the CMOS process, the research field of "sub-10 nm fabrication" has established itself, which represents a wide range of new applications that require nanometre-precise positioning. The dimensions of the substrates (e.g. wafers) and thus the required working range of the positioning systems are constantly increasing. This trend is the central impetus for the further development and research of high-end measuring and production machines and for the need for multi-axis positioning systems that enable nanometre-precise deterministic movements in large working ranges.

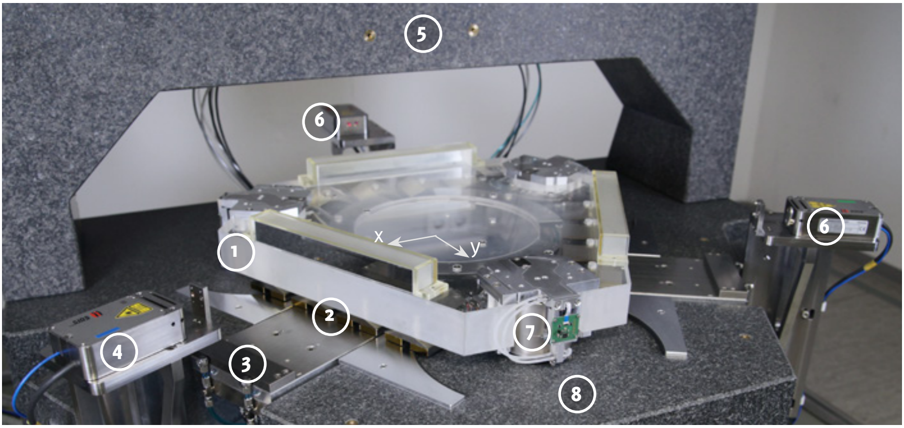

Figure 1: NPS6D200 (1) Slider with reflectors; (2) Magnets of the planar direct drive (move with the slider); (3) Coils of the planar direct drive (encapsulated); (4) Laserinterferometer; (5) Granite portal with interface for the probe system; (6) Laserinterferometer; (7) Lifting module LAU25; (8) Granite stator. Photograph/Graphic: IMMS.

To achieve good controllability and finally servo errors in the nanometre range in the actively controlled axis directions, the basic architecture of the motion system plays an important role. In conventionally structured systems with serially stacked individual axes, long force transmission paths, soft coupling points within the force transmission, low-frequency mechanical resonances or position-dependent changes in the system transmission behaviour can very quickly limit the positioning performance that can be achieved at the point of interest. Parallel kinematic structures offer great potential for improvement here, especially when they are combined with direct force transmission to the moving part and friction-free guidance of the same.

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Direct drive principle as a basic approach

With this basic philosophy, a nanopositioning system controlled in 6 degrees of freedom (6D) for a working range of Ø200 mm (planar) and 25 mm (vertical) was developed at IMMS – the NPS6D200, see Figure 1. The architecture is based on the concept of an integrated planar direct drive for large-scale lateral positioning, as already used for other positioning solutions at IMMS. The main idea behind the new development of the NPS6D200 is to extend this concept to include vertical actuation with a motion distance of 25 mm. Thanks to the flat design of the integrated planar direct drive, vertical adjustment can be achieved directly between the stator and the moving part. In this way, the advantages of the direct drive principle are retained and all drive forces can continue to act directly and contact-free on the same body.

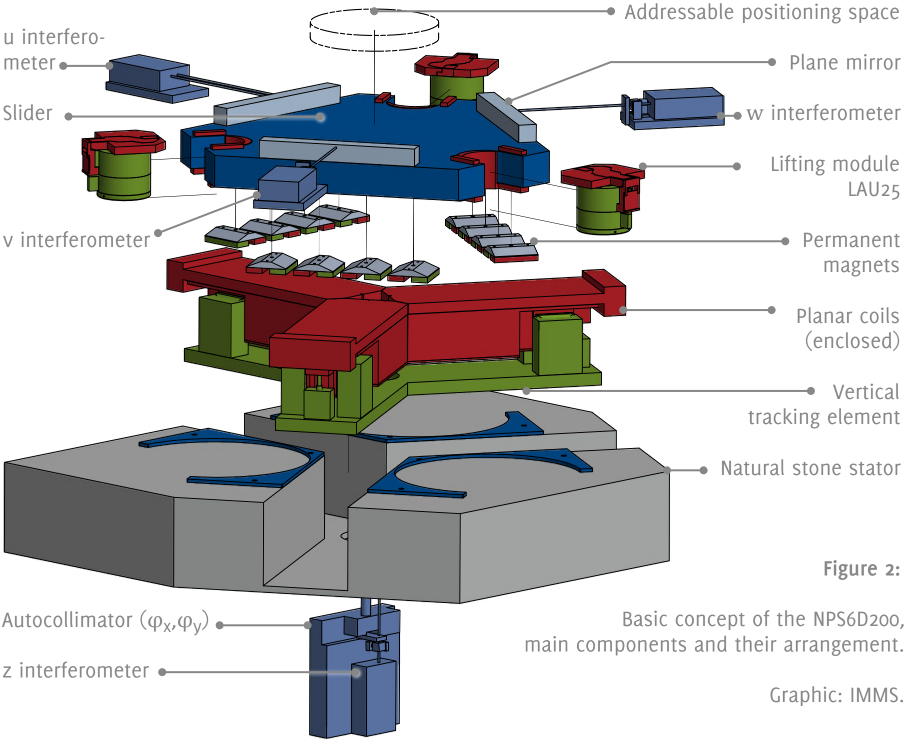

Figure 2:

Basic concept of the NPS6D200, main components and their arrangement.

Graphic: IMMS.

This body is the so-called slider, whose movement is controlled in all six degrees of freedom (DOFs). The displacements in x, y, z are available for large-scale movements, while the rotational degrees of freedom φ_x, φ_y, φ_z are operated as zero-point control.

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Compared to purely planar positioning, vertical adjustment enables a significantly extended range of functions for the resulting overall system:

- Compensation of guiding deviations in z, φ_x, φ_y
- Probing of 3D objects, inclined surfaces and macroscopic step heights
- Applications with vertical displacement, e.g. focus variations in interferometry or contour following with optical or mechanical probing
- Loading/unloading of the measurement object without dismantling the probing or manipulation tool.
- Vertical adjustment using over-actuated lifting modules with aerostatic guidance.

As can be seen in Figure 2, the NPS6D200 is based on a planar drive in a triangular basic configuration and three lifting and actuating units (LAU25), which realise the vertical drive as well as the aerostatic guidance. The integrated direct drive for controlling the planar movement is made up of three linear actuators in a 120° arrangement, each unit consisting of stationary flat coils and a moving magnet array. The three actuators together generate the drive force in the xy plane as well as the torque for addressing the rotation around the vertical axis φ_z. For precise vertical movement of the quartz slider, three lifting modules (LAU25) are positioned at the corners of the triangle and, in combination, cause the displacement in the z-direction and the tilting in the rotational degrees of freedom φ_x and φ_y.

Each LAU25 module combines several functions in a compact, integrated design:
- Dynamic actuator with high bandwidth using voice coil actuator,
- Quasi-static pneumatic actuator for weight compensation,
- Aerostatic guiding for frictionless movement,
- Internal optical encoder for initialisation.

The heart of the lifting modules is a pneumatic actuator that generates low-frequency vertical forces primarily for weight compensation. For this purpose, the pressure in a contactlessly sealed pressure chamber, see figure 3, is controlled individually and with high precision. The non-contact gap seal of the pressure chamber is integrated into the shape of the vertical air guiding, so that friction is consequently avoided as a source of interference and the introduction of disturbances into the system is minimised. While the pneumatic actuator bears the static load, a concentrically arranged and parallel acting voice coil actuator generates the dynamic forces required for high-precision control. As a result, the lifting modules allow the slider's own weight to be carried without any significant power consumption in the voice coil actuators and at the same time its vertical position can be adjusted very sensitively.

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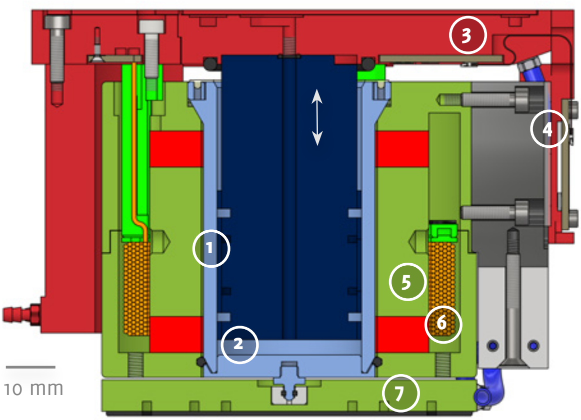

Figure 3:

Sectional view of the LAU25 lifting module: (1) Vertical aerostatic bushing guide; (2) Pressure chamber for pneumatic weight compensation; (3) Vertically moving part (interface to the slider); (4) Encoder measuring system; (5) Voice coil actuator, field part; (6) Voice coil actuator, coil section (moving); (7) planar air bearing.

Graphics: IMMS.

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

Purely force-coupled slider guidance through 6D control

The slider made of quartz glass not only represents the moving part of the drive system, but also contains the reflectors for high-resolution displacement and angle measurement via laser interferometers and a 2D autocollimator. The machine metrology is defined by the arrangement of the reflectors (on the slider) and the measuring heads (on the stator). The closed-loop control of the slider position on the basis of this 6DOF measurement means that the imperfections of the various air guides do not become effective as positioning errors and the accuracy of the slider movement is only determined by the machine metrology and the achievable control performance.

Characteristics of the NPS6D200 system at a glance:

- xyz motion range: Ø 200 mm x 25 mm
- xy speed: 50 mm/s
- z speed: 2 mm/s
- Acceleration: 250 mm/s²
- xyz measurement resolution: 20 pm
- Moved mass: 36 kg
- Payload: 5 kg

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3D nanopositioning in point-to-point mode and on trajectories

When operating with a constant target value, the NPS6D200 achieves an RMS control deviation of less than 1 nm in all three axis directions, see Figure 4. This closed-loop performance is made possible by the consistent implementation of the direct drive principle, the avoidance of internally generated disturbances and, last but not least, a specially developed 6D control of the over-actuated overall system. This enables positioning with steps at nanometre level as well as simultaneous and synchronised movement in all three axes along complex 3D trajectories with nanometre precision. In cross-scale helix tests with dimensions ranging from 40 nanometres to 40 millimetres, path deviations in the low single-digit nanometre range are achieved – Figure 5 shows an example of the measured slider position for a Ø 40 nm x 20 nm helix. At the same time, despite the high moving mass, only a very low current consumption of a few milliamperes can be observed in the vertical actuators.

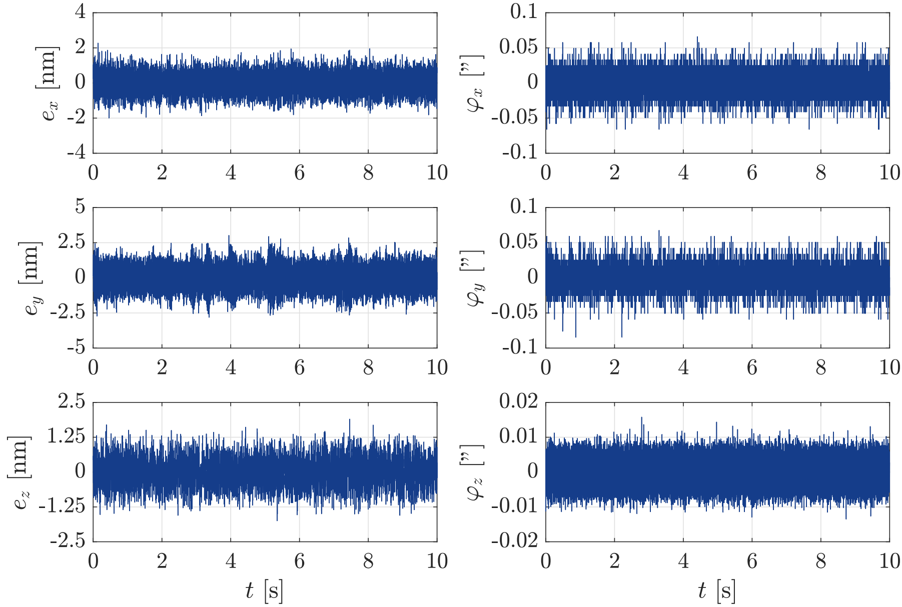

Figure 4: Position time signal in closed-loop operation with constant target value. The RMS control deviation is e_x = 0.47 nm, e_y = 0.68 nm, e_z = 0.41 nm (figure on the left) and $e_{\varphi x}$ = 11.21 m", $e_{\varphi y}$ = 9.83 m", $e_{\varphi z}$ = 3.03 m" (figure on the right). Graphics: IMMS.

This positioning capability demonstrates the suitability of the NPS6D200 for nano-positioning tasks in large 3D working areas, while at the same time generating very little heat and minimising emmisions into the measurement volume. With this combination, the system is well suited as a positioning platform for nanotechnology

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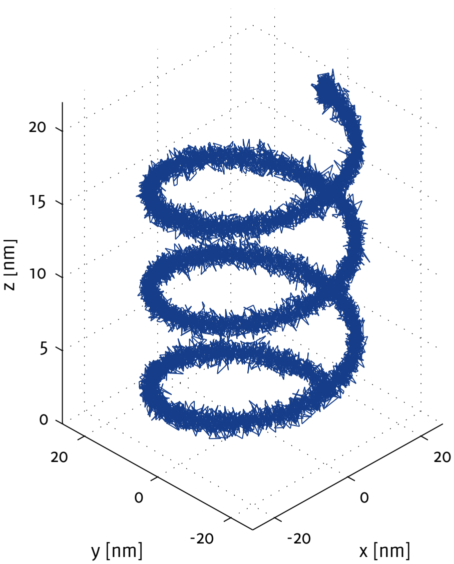

Figure 5:

Position measurement signal of a 3D trajectory, helix: Ø 40 nm x 20 nm (height),

RMS trajectory error:
e_x = 0.71nm,
e_y = 0.88 nm,
e_z = 0.39 nm.

Graphics: IMMS.

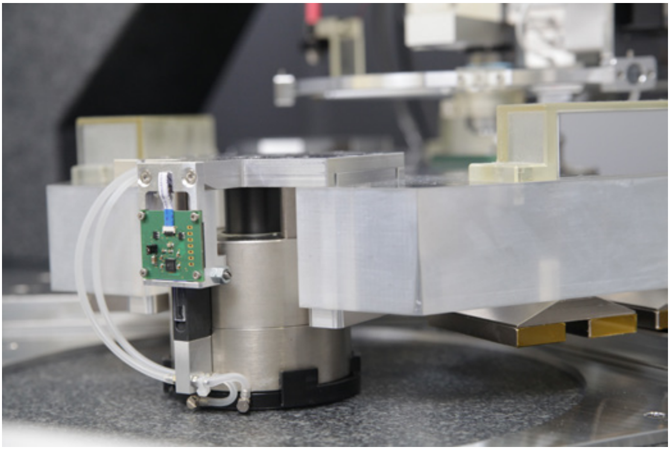

Figure 6:

One of the three LAU25 lifting modules integrated in the NPS6D200 for vertical movements of up to 25 mm.

Photograph: IMMS.

applications that require such precise position control between the tool and substrate up to wafer size on the one hand and that rely on minimised interference in the interaction area on the other, for example wafer-based inspection, long-range AFM scans or sub-10 nm fabrication.

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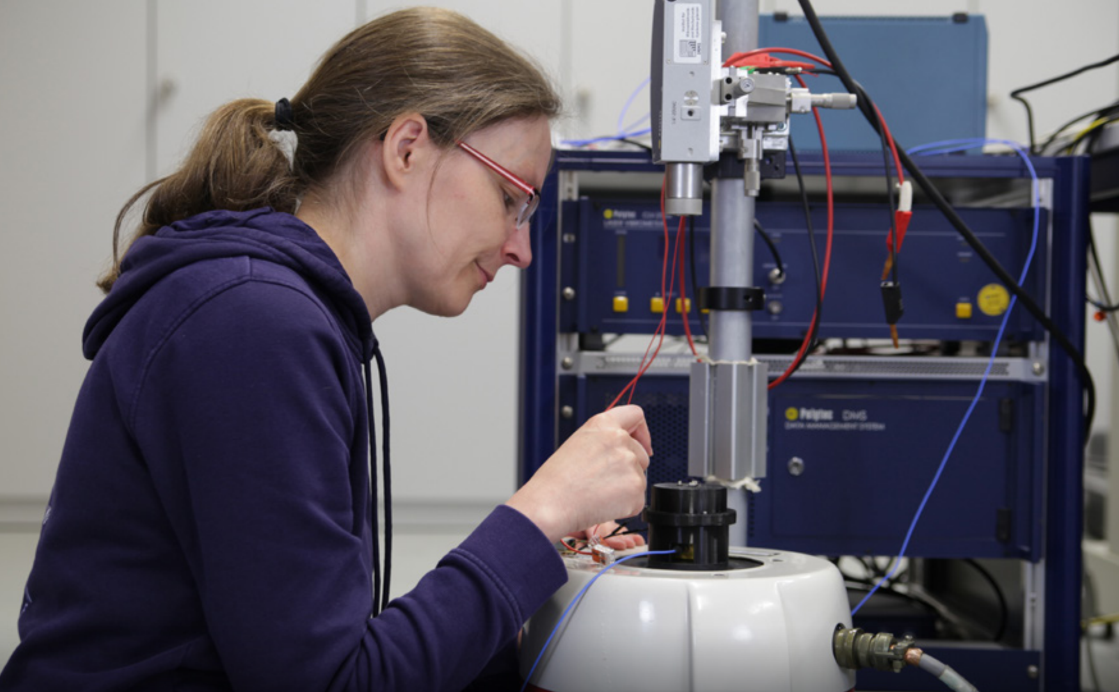
Contact person: Steffen Hesse, steffen.hesse@imms.de

Freistaat Thüringen

Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

Parts of the work presented were carried out in the internal research group NextGenPos and the NanoFab graduate programme. The internal research group ”Next Generation Positioning“ (NextGenPos) was funded by the German Land of Thüringen. 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.

www.imms.de/nanofab



Modelling of electrodynamic energy harvesters

Investigations on a shaker for vibration excitation for research into the modelling of electrodynamic energy harvesters. Photograph: IMMS.

Motivation and overview

Energy harvesters convert ambient energy such as vibrations into electrical energy to operate energy self-sufficient wireless sensor nodes in decentralised or inaccessible locations, for example, and to minimise the necessary maintenance and installation costs. Energy harvesters have been the subject of research for around 30 years, but so far they have only been successful in very few niche applications. The aim of the ECo-Harvester project was therefore to increase the performance of electrodynamic energy harvesters by optimising the overall system. This requires the holistic mathematical modelling of all system components so that the mechanical and electrical subsystems are no longer designed separately in future. On the one hand, it is essential to describe system components on the basis of physical effects and their interactions. On the other hand, it is necessary to combine the findings for standardised modelling at an adapted level of abstraction and for treatment with an adapted simulation and design tool. Together with the project partner Hahn-Schickard-Gesellschaft für angewandte Forschung e.V., various optimisation options

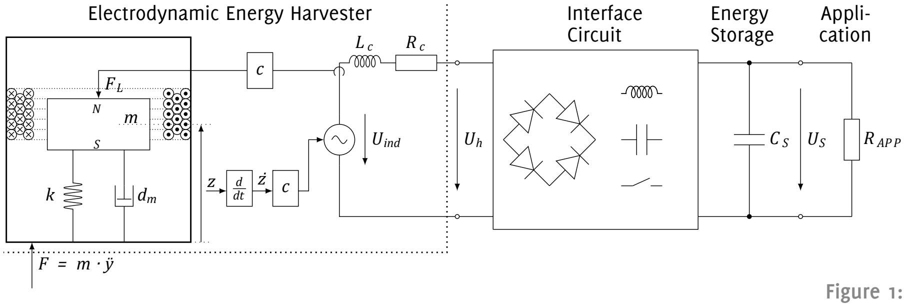


Figure 1:
Schematic of an electrodynamic energy harvester with interface circuit. Graphic: IMMS/Hahn-Schickard.

were investigated for this purpose, through which a large number of parameters can be varied in the shortest possible runtime. The result is a design tool that automatically calculates optimum geometric dimensions for various harvester topologies.

Design tool for modelling the mechanical-electrical conversion

The focus of the work at IMMS was on modelling the mechanical-electrical conversion. Electrodynamic harvesters are based on electromagnetic induction as a result of a time-varying magnetic field within a coil. In typical arrangement structures, the relative movement between the coil and a constant magnetic field is utilised. The number of coils and magnets as well as their arrangement in relation to each other and the addition of different magnetic back irons are variable.

In ECo-Harvester, IMMS has developed a design tool that automatically calculates optimum geometric dimensions for various topologies. It was started in the Green-ISAS research group and has now been extended to include back iron topologies. The tool optimises the electrical output power depending on the available converter volume and the given excitation and takes into account secondary conditions such as the minimum voltage.

www.imms.de/green-isas

According to Figure 1, the moving mass (m) is operated in resonance to the dominant frequency of the excitation by means of a spring stiffness (k). This movement is damped mechanically (d_m) on the one hand and electrically via the Lorentz force (F_L) on the other. The induced voltage results from the product of the speed of the mass and the coupling factor (c). The proportionality factor between the Lorentz force and the coil current is also the same coupling factor.

For the automated design tool, IMMS investigated various options for modelling the coupling factor in ferrous structures. In addition to the number of windings of the coil, the temporal change in the magnetic axial flux surrounded by the coil is also required for the calculation. Due to the source-free nature of the magnetic field, this can be attributed to a calculation of the radial field within the winding window. This can be solved analytically for non-ferrous topologies, but finite element modelling (FEM) is required for structures with back iron due to the field distortion. Two approaches were investigated and compared for the integration of the FEM calculations into the optimisation process: the mapping of the radial flux density using a neural network and the direct FEM coupling during the optimisation.

Optimisation with a neural network

www.imms.de/fem

For the application of a neural network using multi-layer perceptron regression, it was first investigated which characteristic variables can be used to abstract the radial magnetic flux density. It was found that the mean value in the entire winding window can be approximated by the curve in the centre of the coil. The characteristic curve of the centre of the coil is mapped by unevenly distributed supporting points with an increased density in the area of the maximum flux density. The number of supporting points has an influence on the accuracy of the results, but also on the computational effort. In the investigations carried out, 9 or 11 sampling points and spline interpolation were used to achieve deviations of less than 2%. All design parameters were varied for the analysed topologies and the field results were generated and saved using ANSYS Maxwell. The input and output variables of the data were scaled to the minimum and maximum values for each topology and served as training data for the investigation of various neural networks.

As a result, very good matches between the derived model and the original data were achieved using this method. However, the deviations increase significantly when the data has to be extrapolated. This means that the model is only valid for a trained size range. New training data must also be generated for new topologies, which takes several days to weeks depending on the computing technology available.

Optimisation via finite element coupling

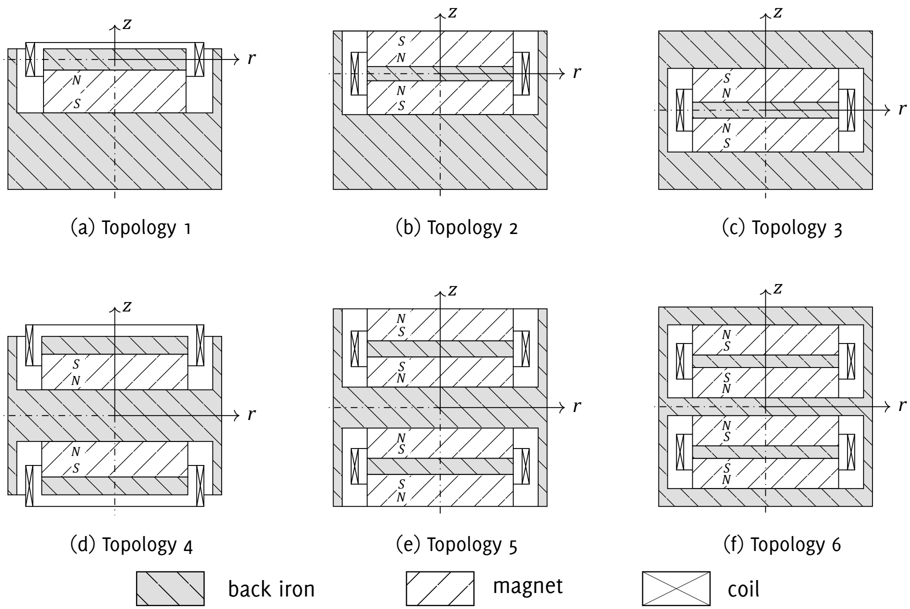
As a second method, the direct FEM coupling during the optimisation process was implemented in Python. The Python library PyAEDT was used for this, which provides the interface between Python and the Ansys Electronics Desktop programme and which saw rapid development during the project term. To achieve a fast FEM calculation in each optimisation step, investigations were carried out into necessary but not too computationally intensive meshing settings. In particular, the coil windows in which the field is analysed are initially meshed so that the automatic mesher can be limited to three iterations.

Results

The variant with direct coupling was incorporated into the design tool, as this was the most target-oriented option for the comparison of different topologies carried out in the project due to the modular expansion options.

The topologies currently being analysed are shown in Figure 2. These are standard topologies for a cylindrical installation space and with increasing complexity, particularly with regard to production.

Figure 2: Implemented topologies in increasing complexity. Graphic: IMMS.



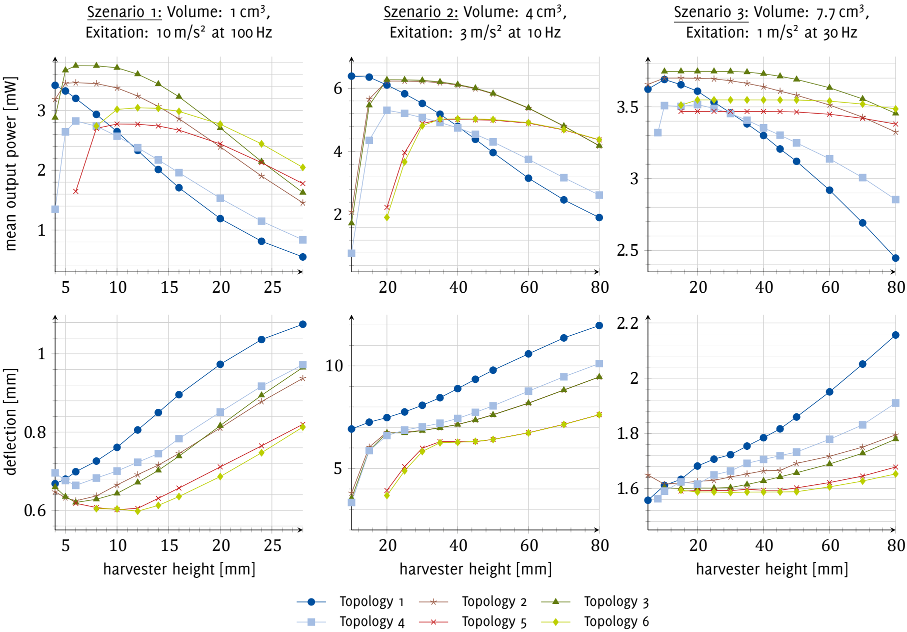


Figure 3: Exemplary comparative study. Topology 3 (see Figure 2) generates the maximum output power per volume for the boundary conditions under consideration. Graphic: IMMS.

With the help of the developed design tool, the topologies were analysed with regard to their suitability for different boundary conditions and aspect ratios for various application conditions. In contrast to earlier investigations on ironless structures, no significant difference was found in the current study between the suitability of the topologies for scenarios with relatively small amplitudes compared to large amplitudes. In all scenarios, it was shown that for the boundary conditions considered, topology 3 with two opposing magnets and a closed back iron generates the maximum output power per volume, see Figure 3. If the aspect ratio is limited, other topologies can also produce better results, especially for very flat or very high structures.

Outlook

With the status developed in ECo-Harvester, IMMS is able to create application-specific designs according to customer requests in the shortest possible time. The results achieved also form the basis for script-based FEM analyses with pyAnsys. In addition to energy harvesting, these also offer a high degree of flexibility and automation in other areas compared to classic GUI-based modelling. Python scripts can be used to create repeatable workflows, carry out parameter variations efficiently and automate complex simulation processes. This leads to significant time savings, especially for series analyses or optimisation tasks.

Contact person: Dipl.-Ing. Bianca Leistritz, bianca.leistritz@imms.de

Funded by

Deutsche Forschungsgemeinschaft
German Research Foundation

The ECo-Harvester project was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under the reference 452215927.

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PROOF THROUGH FACTS AND FIGURES

Test setup for the SPAD-based sensor developed in the FluoResYst project for the time-resolved readout of fluorescence-labelled DNA microarrays.

Photograph: IMMS.

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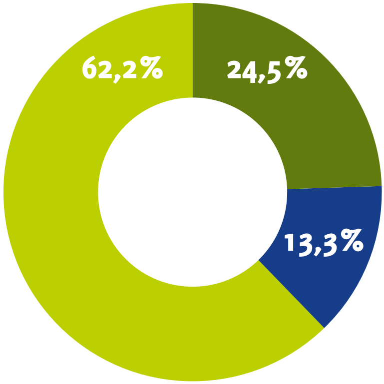
In 2024, the FluoResYst project was funded as part of the Photonics Research funding programme by the German Federal Ministry of Education and Research (BMBF) under the reference 13N15807.

Facts and figures in 2024

At the end of the 2024 financial year, 98 **employees** of various nationalities and specialisations were working at IMMS.[1]

Staff structure



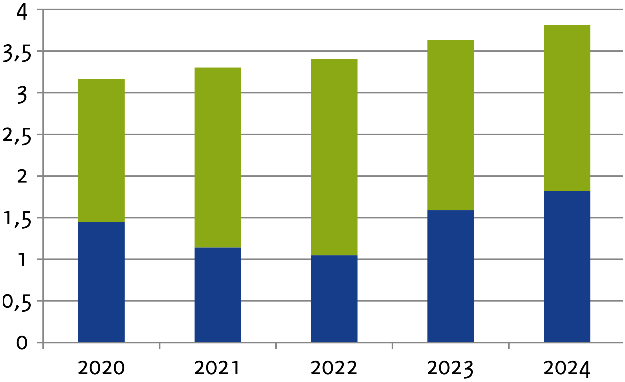
Scientists | Students | Administration / apprentices

Of these, 61 scientists and 24 students were employed in research and development. This corresponds to around 87 % of all employees. In addition, 4 of the 13 employees assigned to administration were directly employed to support research.

As part of training in practice-oriented research, a total of 38 students were supervised at IMMS in the financial year, including 2 Bachelor's theses and 5 Master's theses. 7 employees were enrolled as doctoral students at a university and 3 of them successfully completed their doctorates in 2024.

The financial year developed well in economic terms. **Third-party funding earnings** increased once again compared to the already high earnings of the previous year. The driving force behind this growth was industrial contract research (industrial projects), which reached an all-time high with an increase of 15 % compared to the previous year. Around 66 industrial projects were processed in the financial year. Due to (limited) personnel capacity, earnings from publicly funded research projects (sponsored projects) remained at the previous year's level. In the 2024 financial year, 4 publicly funded research projects (sponsored projects) were started and a total of 15 were being carried out.

1 *The employee figures as of 31 December 2024 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

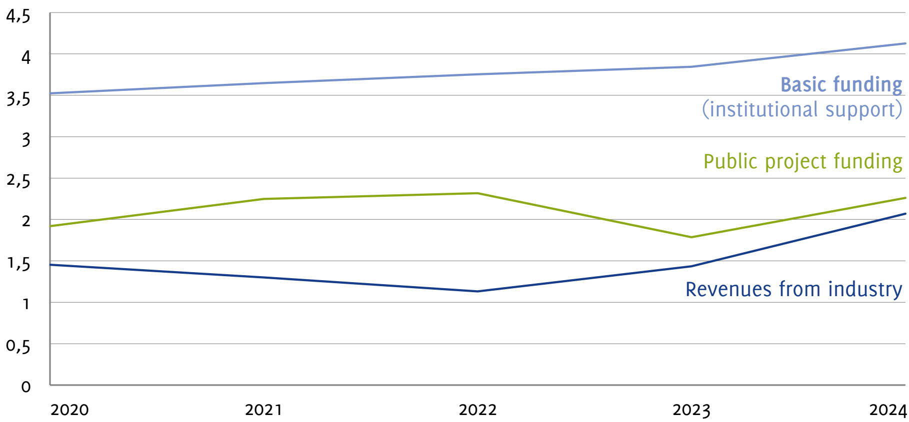
Industrial projects

The internal research groups that were funded by the German Land of Thüringen and whose research topics are important for the strategic development of IMMS were successfully completed in the 2024 financial year.

In the 2024 financial year, the Institute's funding (revenues) again consisted of three financing components: publicly funded research projects (funded projects), industrial contract research (industrial projects) and **institutional funding** from the German Land of Thüringen. Funding from Thüringen remains the indispensable basis for IMMS' research activities. However, the importance of industrial contract research for the growth of the institute is increasing.

www.imms.de/funding

Pillars of financial support in million €



Organisation as of 31 December 2024

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Proprietor German Land of Thüringen

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Mechatronics Ludwig HERZOG, Dr.-Ing.

System Design Tino HUTSCHENREUTHER, Dr.-Ing.

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› *Distributed measurement + test systems*
› *nm-precise 6D direct drives*
› *Contents*
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Lectures, lecture series

Prof. Dr. Ralf Sommer
at Technische Universität Ilmenau, 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,
at Technische Universität Ilmenau, 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

Events

Conferences / events with contributions by IMMS

www.imms.de/events

19/02/2024 – AI Breakfast – Thuringian Centre for Business Start-ups and Entrepreneurship, IHK Erfurt, *talk*, Erfurt
25/02/2024 – TuZ 2024 – 36th ITG / GMM / GI -Workshop Test Methods and Reliability of Circuits and Systems, *talk*, Darmstadt
05/03/2024 – EBL 2024 – 12th GMM/ DVS symposium: Electronic assemblies and printed circuit boards – sustainability and energy efficiency with smart electronics, *talk*, Fellbach
17/03/2024 – CSTIC 2024 – Conference of Science & Technology for Integrated Circuits (CSTIC) in conjunction with SEMICON China 2024, *talk*, Shanghai, China
19/03/2024 – EASS 2024 – 12th GMM Conference on Energy Autonomous Sensor Systems, *talk*, Freiburg
26/03/2024 – ZAKI Workshop – AI is changing production processes, *talk*, Jena
09/04/2024 – edaWorkshop 2024 – edaWorkshop24 and the European Nanoelectronics Applications, Design & Technology Conference (ADTC), *talk*, *poster*, Dresden
17/04/2024 – POCT – Point-of-Care Diagnostics: Innovations from assays, microfluidics to production, *poster*, Leipzig

24/04/2024 – IT-KOM – Career Fair of the Applied Computer Science Department, University of Applied Sciences Erfurt, *talk, exhibition booth, demonstrator,* Erfurt

29/05/2024 – IEEE MetroInd4.0&IoT 2024 – IEEE International Workshop on Metrology for Industry 4.0 & IoT, *talk,* Florenz

03/06/2024 – ISSW 2024 – The International SPAD Sensor Workshop & SPAD Sensor School, *talk*, Trento, Italy

04/06/2024 – IEEE RFID 2024 – 18th Annual International Conference on RFID, *talk*, Boston, MA

04/06/2024 – Days of trustworthy electronics 2024 – Presentations of the results of the research projects of the funding guidelines for trustworthy electronics (ZEUS) and future-proof special processors and development platforms (ZuSE) of the Federal Ministry of Education and Research (BMBF), *3 posters,* München

06/06/2024 – Chipdesign Germany – Microelektronics Design Initiative, *poster*, Hannover

29/06/2024 – HAM RADIO 2024 – International Amateur Radio Exhibition, *talk*, Friedrichshafen

02/07/2024 – SMACD 2024 – International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD), *3 talks*, Volos, Griechenland

05/08/2024 – FPGA Ignite Summer School – Networking, lectures and a hackathon on designing a custom RISC-V SoC, *poster*, Heidelberg

06/08/2024 – 5 Years of EXPRESS – Central German network meeting of the EXPRESS experimental field, *4 posters*, Meißen

03/09/2024 – Results conference of the digital experimental fields – Federal Office for Agriculture and Food (BLE), *talk*, Berlin

22/10/2024 – 8th Thuringian Mechanical Engineering Day – The challenge of labour shortages – what can companies do? Best practice and new approaches, *talk, exhibition booth, demonstrator,* Erfurt

23/10/2024 – ICPE 2024 – The 20th International Conference on Precision Engineering, *talk*, Sendai, Japan

07/11/2024 – Bernburg Irrigation Day – Sustainability in irrigated agriculture – digital experiences and solutions, *2 posters, demonstrators,* Bernburg

12/11/2024 – euspen SIC – euspen Special Interest Conference: Precision Motion Systems & Control, *1 talk, 2 posters*, 's-Hertogenbosch, The Netherlands

25/11/2024 – DSS 2024 – 17. Dresden Sensor Symposium, *posters*, Dresden

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05/12/2024 – Master meets machine – The Craft Festival. Conference with accompanying exhibition, *talk, exhibition booth,* Erfurt

06/12/2024 – SME Digital event – Artificial intelligence and sustainability – how AI can help save energy and resources, *talk, organisation*, online

18/12/2024 – IEEE RFID-TA 2024 – Forum for advancing RFID technology and practice, *talk*, Daytona Beach, FL, USA

Workshops / IMMS as host, organiser or co-initiator

16/01/2024 – SME Digital: AI Regulars' Table – "How the SPEAKER and OpenGPT-X projects are driving forward dialogue-oriented AI 'made in Germany'", *co-organiser, moderation,* Ilmenau

03/04/2024 – Research day for teenagers, *event at IMMS,* Ilmenau

18/04/2024 – SME Digital: Industry Forum Smart Manufacturing I – "Digital twin and digital product passport", *organisation, moderation,* Saalfeld

25/04/2024 – Girls'Day 2024, *event at IMMS,* Ilmenau

11/06/2024 – SME Digital: AI Regulars' Table – "TEEMSC – A self-learning approach to enable energy-efficient machine diagnostics on microcontrollers", *organisation and moderation,* online

05/09/2024 – SME Digital: 4th IT Security Day – "Equipped for the future: recommendations for action and solutions", *co-organiser*, Erfurt

10/09/2024 – SME Digital: AI Regulars' Table & Meetup of the AWS MeetUp Group Ilmenau with the BVMW – "AI and knowledge management in companies", *organisation, moderation*, Ilmenau

10/09/2024 – SME Digital: Industry Forum Smart Manufacturing II – "Digital twin and digital product passport", *organisation, moderation,* Kölleda

19/09/2024 – edaBarCamp: EPISODE VI – Return of the edaBarCamp, *co-organiser, "participutor",* Neubiberg/München

14/10/2024 – SME Digital: Cross Cluster Week 2024 – CCIT kick-off event "Resilient through cooperation", *co-organiser, exhibition booth,* Erfurt

06/11/2024 – SME Digital: AI Regulars' Table with Navigator bus, *organisation,* Ilmenau

08/11/2024 – Long Night of Science in Erfurt – hands-on activities and career and study guidance: Thuringian Universities present at CiS, Fraunhofer-Zentrum, IMMS, Melexis and X-FAB, *event at IMMS, demonstrators,* Erfurt

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28/11/2024 – SME Digital: Digital and physical security in companies – Live demonstration, *organisation, moderation*, Ilmenau
06/12/2024 – SME Digital: Artificial intelligence and sustainability – How AI can help save energy and resources, *talk, organisation*, online
10/12/2024 – SME Digital: AI Regulars' Table – "Signal evaluation in acoustic process monitoring of laser welding processes in the ultrasonic range: Does it need AI?", *organisation, moderation,* online

Trade fairs and exhibitions

08/04/2024 – 16th Erfurt Technology Dialogue – Research and Industry Centre Erfurt, *exhibition booth, demonstrator,* Erfurt
17/04/2024 – Data Week Leipzig 2024 – K-M-I transfer day, *exhibition booth, demonstrator,* Leipzig
24/04/2024 – IT-KOM – Career Fair of the Applied Computer Science Department, University of Applied Sciences Erfurt, *talk, exhibition booth, demonstrator,* Erfurt
07/05/2024 – HAW Fair – Career fair of the Hamburg University of Applied Sciences (HAW), *exhibition booth, demonstratoren,* Hamburg
14/05/2024 – Career opportunities for engineers – Information and networking events for students at the University of Duisburg-Essen, *exhibition booth, demonstrators,* Duisburg
15/05/2024 – InnoCON Thüringen 2024 – TransferXThüringen: Sharing knowledge, create innovations, *exhibition booth, demonstrators,* Weimar
04/06/2024 – Symposium of SaaleWirtschaft e.V. – Artificial intelligence and IT security, *exhibition booth, demonstrator,* Rudolstadt
18/06/2024 – erwicon – Erfurt Business Congress: Innovations in action – discover, experience, design, *exhibition booth*, Erfurt
19/06/2024 – Career Dates – Career fair at the Leibniz University Hannover, *exhibition booth, demonstrator,* Hannover
26/09/2024 – DGFT Conference "Precision engineering design", *exhibition booth, demonstrators*, Dresden
16/10/2024 – elmug4future 2024 – technology conference on hydrogen and measurement technology, *exhibition booth, demonstrators*, Erfurt
22/10/2024 – 8th Thuringian Mechanical Engineering Day – The challenge of labour shortages – what can companies do? Best practice and new approaches, *talk, exhibition booth, demonstrator,* Erfurt

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23/10/2024 – inova 2024 – The career forum at Technische Universität Ilmenau, *exhibition booth, demonstrator,* Ilmenau
29/10/2024 – 6th Thuringian AI Forum – Innovations, trends and experiences – AI as a driving force for Thüringen, *exhibition booth, demonstrator,* Erfurt
13/11/2024 – Precision Fair – The premier trade fair for high and ultra-precision technology, *exhibition booth, demonstrator,* ‘s-Hertogenbosch, The Netherlands
05/12/2024 – Master meets machine – The Craft Festival. Conference with accompanying exhibition, *talk, exhibition booth,* Erfurt

Video productions

Change of perspective: Largest instead of smallest “circuit board” “installed” at IMMS; *https://youtu.be/g43-D-yKcxU*

6D Nanometer Planar Positioning System for ultra precision and large motion range positioning tasks; *https://youtu.be/r3PKo82sfvs*

Long Night of Science in Erfurt 2024; *https://youtu.be/yBNx18nzxHQ*

www.imms.de/videos

Reviewed publications

High-Sensitive Demodulator with Built-in Negative Offset Comparator for Passive UHF RFID Tags, Rohit KESHARWANI[1]. Andre JÄGER[1]. Martin GRABMANN[1]. Georg GLÄSER[1]. Eric SCHÄFER[1]. *IEEE RFID-TA 2024, Forum for advancing RFID technology and practice, Daytona Beach, FL, USA, December 18–20, 2024*. DOI: in progress. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Impact of Real-World Energy Consumption Variance on Internet of Things Node Lifetime Predictions. Silvia KRUG[1,2], Tino HUTSCHENREUTHER[1], Hannes TOEPFER[1,3]. Mattias O'NILS[2]. *Electronics 2024, 13, 4578*. **DOI: https://doi.org/10.3390/electronics13234578**. [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Department of Electronics Design, Mid Sweden University, Holmgatan 10, 851 70 Sundsvall, Sweden. [3]Technische Universität Ilmenau, Advanced Electromagnetics Group, Ilmenau, Germany.

Investigation of distance measurement reproducibility for a long-range nanopositioning machine combined with a laser focus sensor, Davi Anders BRASIL[1]. Steffen HESSE[1]. Michael KATZSCHMANN[1]. Ludwig HERZOG[1]. Thomas FRÖHLICH[2]. Thomas KISSINGER[2]. *20th International Conference on Precision Engineering (ICPE2024), Sendai, Japan, October 23-26, 2024.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Institute of Process Measurement and Sensor Technology, Technische Universität Ilmenau, Ilmenau, Germany.

Towards Measuring and Forecasting Noise Exposure at the VELTINS-Arena in Gelsenkirchen, Germany, Pitchapa NGAMTHIPWATTHANA[1]. Marco GÖTZE[2]. András KÁTAI[1]. Jakob ABEßER[1]. *2024 IEEE 5th International Symposium on the Internet of Sounds (IS2), Erlangen, Germany, 30 September – 2 October, 2024, pp. 1-8,* **DOI: https:// doi.org/10.1109/IS262782.2024.10704088.** [1]Fraunhofer Institute for Digital Media Technology (IDMT), Ilmenau, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

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NPS6D200 – A Long Range Nanopositioning Stage with 6D Closed Loop Control, Steffen HESSE[1]. Alex HUAMAN[1]. Michael KATZSCHMANN[1]. Bianca LEISTRITZ[1]. Ludwig HERZOG[1]. Appl. Sci. 2024, 14, 6972. **DOI: https://doi.org/10.3390/app14166972.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Set the Clock: A Synthesizable Clock Manager, Jonas LIENKE[1]. Florian KÖGLER[1]. Eric SCHÄFER[1]. Georg GLÄSER[1]. *2024 20th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD), Volos, Greece, July 02-05, 2024. pp. 1-4,* **DOI: https://doi.org/10.1109/SMACD61181.2024.10745390.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Propagation Delay Estimation for Mixed-Signal Modeling of Comparators, Martin GRABMANN[1]. Eric SCHÄFER[1]. Georg GLÄSER[1]. *2024 20th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD), Volos, Greece, July 02-05, 2024. pp. 1-4,* **DOI: https://doi.org/10.1109/SMACD61181.2024.10745467.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Integrating Multiple Knowledge-based Automation Methodologies into the A/MS IC Design Flow, Benjamin PRAUTSCH[1]. Ralf SOMMER[2,3]. Jürgen SCHEIBLE[4]. Uwe EICHLER[1]. Lorenz RENNER[2]. Till MOLDENHAUER[4]. Matthias SCHWEIKARDT[4]. Yannick UHLMANN[4]. *2024 20th International Conference on Synthesis, Modeling, Analysis and Simulation Methods and Applications to Circuit Design (SMACD), Volos, Greece, July 02-05, 2024. pp. 1-4,* **DOI: https://doi.org/10.1109/SMACD61181.2024.10745465.** [1]Division Engineering of Adaptive Systems, Institute for Integrated Circuits, Fraunhofer IIS/EAS, Dresden, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [3]Technische Universität Ilmenau, Electrical Engineering and Information Technology, Electronic Circuits and Systems Group, Ilmenau, 98693, Germany. [4]Electronics & Drives, Reutlingen University, Reutlingen, Germany.

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Enhancing Chemiluminescence-Detection with Dark-Count Rate Optimization Strategies for SPADs in Conventional CMOS Technologies, Benjamin SAFT[1]. Alexander ZIMMER[2]. Maximilian WIENER[1]. Mirjam SKADELL[2]. Eric SCHÄFER[1]. *ISSW 2024, The International SPAD Sensor Workshop & the SPAD SENSOR SCHOOL, Trento, Italy, June 3 – 6, 2024.* In IISS Online Library: **https://imagesensors.org/2024-international-spad-sensor-workshop/.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]X-FAB Semiconductor Foundries GmbH, Erfurt, Germany.

A Charge Pump System with Controlled Input Impedance for Optimized RFID Energy Harvesting, Rohit KESHARWANI[1]. Andre JÄGER[1]. Martin GRABMANN[1]. David SCHREIBER[1]. Georg GLÄSER[1]. Hani ABDULLAH[1]. Eric SCHÄFER[1]. *2024 IEEE International Conference on RFID (RFID), Boston, MA, USA, June 4-6, 2024,* **DOI: https://doi.org/10.1109/RFID62091.2024.10582749.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

TEEMSC – Trainable Energy Efficient Machine Diagnosis using Singular Values and Canonical Crosscorrelation, Rick PANDEY[1]. Sebastian UZIEL[1]. Tino HUTSCHENREUTHER[1]. Silvia KRUG[1,2]. *IEEE International Workshop on Metrology for Industry 4.0 and IoT, Florence, Italy, May 29-31, 2024,* **DOI: https://doi.org/10.1109/MetroInd4.0IoT61288.2024.10584173.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Department of Computer and Electrical Engineering, Mid Sweden University, Holmgatan 10, 851 70 Sundsvall, Sweden.

Investigations on tip-based large area nanofabrication and nanometrology using a planar nanopositioning machine (NFM-100), Jaqueline STAUFFENBERG[1]. Johannes BELKNER[1]. Denis DONTSOV[2]. Ludwig HERZOG[3]. Steffen HESSE[3]. Ivo W. RANGELOW[1,4]. Ingo ORTLEPP[1]. Thomas KISSINGER[1]. Eberhard MANSKE[1]. *2024 Meas. Sci. Technol. 35 085011,* **DOI: https://doi.org/10.1088/1361-6501/ad4668.** [1]Institute for Process Measurement and Sensor Technology, Department for Mechanical Engineering, Gustav-Kirchhoff-Straße 1, Ilmenau, Germany. [2]SIOS Meßtechnik GmbH, Am Vogelherd 46, 98693 Ilmenau, Germany. [3]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [4]nano analytik GmbH, Ehrenbergstraße 1, 98693 Ilmenau, Germany.

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Enhancing Apple Cultivar Classification Using Multiview Images, Silvia KRUG[1,2]. Tino HUTSCHENREUTHER[2]. *J. Imaging 2024, 10, 94.* **DOI: https://doi.org/10.3390/jimaging10040094,** [1]Department of Computer and Electrical Engineering, Mid Sweden University, Holmgatan 10, 851 70 Sundsvall, Sweden. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

A Retrofit Streetlamp Monitoring Solution Using LoRaWAN Communications, Sören SCHNEIDER[1]. Marco GÖTZE[1]. Silvia KRUG[1, 2]. Tino HUTSCHENREUTHER[1]. *Eng 2024, 5, 513-531,* **DOI: https://doi.org/10.3390/eng5010028,** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Department of Computer and Electrical Engineering, Mid Sweden University, Holmgatan 10, 851 70 Sundsvall, Sweden.

SPAD-Based Sensor IC for chemiluminescence assays in microfluidic channels, Alexander ZIMMER[1]. Benjamin SAFT[2]. Maximilian WIENER[2]. Jakob HAMPEL[2]. Mirjam SKADELL[1]. Eric SCHÄFER[2]. *Conference of Science & Technology for Integrated Circuits (CSTIC), Shanghai, China, March 17-18, 2024,* **DOI: https://doi.org/10.1109/CSTIC61820.2024.10531988,** [1]X-FAB Global Services GmbH, Erfurt, Germany. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Talks and specialist posters

Miniaturisierte CMOS-basierte Multi-Sensor-Plattform für die Analytik und Diagnostik, Alexander HOFMANN[1]. Florian KÖGLER[1]. Elisa HILBRECHT[1]. Victoria DIMOVA[1]. Eric SCHÄFER[1]. *17. Dresdner Sensor-Symposium, 25. – 27. November 2024, Dresden*, **DOI: https://doi.org/10.5162/17dss2024/P38.** [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Disturbance rejection in periodic motion with enhanced constant velocity transitions using a tilt-mirror test setup, Alex S. HUAMAN[1]. Michael KATZSCHMANN[1]. Steffen HESSE[1]. Ludwig HERZOG[1]. *euspen Special Interest Conference: Precision Motion Systems and Control, Brabanthallen, 's-Hertogenbosch, The Netherlands, November 12-13, 2024.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

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Experimental investigation of air bearing noise by means of a 3D nanopositioning system, Parastoo SALIMITARI[1]. Steffen HESSE[1]. Michael KATZSCHMANN[1]. Alex S. HUAMAN[1]. Ludwig HERZOG[1]. *euspen Special Interest Conference: Precision Motion Systems and Control, Brabanthallen, 's-Hertogenbosch, The Netherlands, November 12-13, 2024.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

NPS6D200 – Realization of high precision long stroke vertical actuation in conjunction with a planar direct drive, Steffen HESSE[1]. Michael KATZSCHMANN[1]. Alex S. HUAMAN[1]. Davi-Anders BRASIL[1]. Ludwig HERZOG[1]. *euspen Special Interest Conference: Precision Motion Systems and Control, Brabanthallen, 's-Hertogenbosch, The Netherlands, November 12-13, 2024.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Neue Ansätze in der Kunststoffproduktion – Ein KI-basiertes Assistenzsystem für den Spritzgießprozess, Dominik SCHRAML[1]. Silvia KRUG[2]. *Thüringer Maschinenbautag, Erfurt, 22. Oktober 2024.* [1]Steinbeis Qualitätssicherung und Bilderverarbeitung GmbH, Ilmenau. [2]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Methoden der digitalen Entwicklungsstadienerkennung im Wein- und Obstbau, Silvia KRUG[1]. Martin SCHIECK[2]. *Ergebniskonferenz der digitalen Experimentierfelder (Express), 4. September 2024, Berlin.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Universität Leipzig, Institut für Wirtschaftsinformatik, 04109 Leipzig, Germany.

Clock Gate Insertion with a Yosys-based Netlist Modification Tool, Manuel JIRSAK[1]. Adrian PITTERLING[1]. Jonas LIENKE[1]. Georg GLÄSER[1]. *FPGA Ignite Summer School, 5. – 9. August 2024, Heidelberg, Germany.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Wie wird mein Unternehmen KI-ready? Bedarfsgerechte Analyse- und Unterstützungspotenziale für KMU durch eine institutionsübergreifende Zusammenarbeit, Sebastian GERTH[1, 4]. Martin FOLZ[2, 4]. Wolfram KATTANEK[3,4]. *Mittelstand-Digital Magazin „Wissenschaft trifft Praxis", Ausgabe 22, „KI-Readiness".* [1]Mittelstand-Digital Zentrum Ilmenau (TU Ilmenau). [2]Mittelstand-Digital Zentrum Chemnitz (TU Chemnitz). [3]Mittelstand-Digital Zentrum Ilmenau (IMMS GmbH). [4]KI-Hub Sachsen-Thüringen.

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Einstieg in die HF-(Mess-)Technik, Björn BIESKE[1]. *HAM Radio, Internationale Amateurfunk-Ausstellung, 28. – 30. Juni 2024, Friedrichshafen, Germany.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

DI-Meta-X: Bridging the Gap with Meta Formats, Georg GLÄSER[1]. Melanie WILHELM[2]. Robert FISCHBACH[3]. Detlef BILLE[4]. Jan MEHNER[5]. Peter KREUTZIGER[6]. *Auftaktveranstaltung Chipdesign Germany, 6. – 7. Juni 2024, Hannover.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]X-FAB Global Services GmbH, Erfurt, Germany. [3]Technische Universität Dresden, Dresden, Germany. [4]EDC Electronic Design Chemnitz GmbH, Chemnitz, Germany. [5]i-ROM GmbH, Neukirchen bei Chemnitz, Germany. [6]AMAC ASIC- und Mikrosensoranwendung Chemnitz GmbH, Chemnitz.

VE-ARiS: Elektronischer Knowhow-Schutz für innovative Sensorsysteme. Abwehr von Reserve-Engineering auf IC-Ebene, Projektkonsortium VE-ARiS (iC-Haus GmbH. Wachendorff Automation GmbH & Co. KG. IMMS GmbH). *Tage der vertrauenswürdigen Elektronik 2024, 4. – 5. Juni 2024, München*

VE-ARiS: Alberich und die Tarnkappenfabrik. SKAW – Schaltungskopierbarkeitsanalysewerkzeug, Adrian PITTERLING[1]. Florian KÖGLER[1]. Georg GLÄSER[1]. *Tage der vertrauenswürdigen Elektronik 2024, 4. – 5. Juni 2024, München.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

What The Fuzz (WTF): A Framework for Fuzz Testing ASIC Designs, Henning SIEMEN[1]. Georg GLÄSER[1]. *Tage der vertrauenswürdigen Elektronik 2024, 4. – 5. Juni 2024, München.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany.

Effect of spent mushroom compost mulch and irrigation treatment on growth, yield and fruit quality of sweet cherry in a summer-dry climate, Martin PENZEL[1]. Claudia KUHAUPT[2]. Maria BAMBERG[3]. Silvia KRUG[4,5]. *European Horticulture Congress EHC, Symposia „Fruit Production Systems for Sustainable and Resilient Development", Bucharest, Romania, May 12-16, 2024.* [1]Lehr- und Versuchszentrum Gartenbau Erfurt, Germany. [2]Thüringer Landesamt für Landwirtschaft und Ländlichen Raum, Erfurt, Germany. [3]Thüringer Landesamt für Bodenmanagement und Geoinformation, Erfurt, Germany. [4]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [5]Department of Computer and Electrical Engineering, Mid Sweden University, Holmgatan 10, 851 70 Sundsvall, Sweden.

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Integration of Chemiluminescence-based SPARCL® Assay on Microfluidic Platform with SPAD-based CMOS Line Sensor IC for Rapid Cytokine Detection, Benjamin Saft[1]. Biljana Gjurova[2]. Pia Scholz[2]. Ana Leonor Heitor Lopes[2]. Alexander Zimmer[3]. Mirjam Skadell[3]. Susann Allelein[2]. Eric Schäfer[1]. *POCT Meeting 2024, 17. – 18. April 2024, Leipzig.* [1]IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH, Ehrenbergstraße 27, 98693 Ilmenau, Germany. [2]Fraunhofer IZI, Leipzig, Germany. [3]X-FAB Global Services GmbH, Erfurt, Germany.

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Abbreviations

6D *6 Degrees of freedom*

ADRC *Active Disturbance Rejection Control*

AE-AD *Autoencoder Anomaly Detection*

AFM *Atomic Force Microscopy*

AHB *AMBA High-performance Bus (AMBA: Advanced Microcontroller Bus Architecture)*

AI *Artificial Intelligence*

API *Application Programming Interface*

ASIC *Application-specific Integrated Circuit*

BLE *Bluetooth Low Energy*

CCA *Canonical Crosscorrelation Analysis*

CLIA *Chemiluminescence Immunoassay*

CMOS *Complementary metal–oxide Semiconductor*

CNN *Convolutional Neural Networks*

CPU *Central Processing Unit*

CSV *Comma-seperated Values*

DOFs *Degrees of Freedom*

DWD *Deutscher Wetterdienst, German weather service*

EDA *Electronic Design Automation*

FEM *Finite Element Modelling*

FFT *Fast Fourier Transformation*

FPGA *Field Programmable Gate Array*

gRPC *Google Remote Procedure Calls*

HDL *Hardware Description Language*

I²C *Inter-Integrated Circuit*

IC *Integrated Circuit*

IoT *Internet of Things*

JSON *JavaScript Opject Notation*

LSTM-AD *Long Short-Term Memory Anomaly Detection*

MCU *Microcontroller Unit*

MinIO/S3 *Cloud memory*

MQTT *Message Queueing Telemetry Transport*

PCB *Printed Circuit Board*

PMT *Photomultiplier Tube*

QSPI *Quad SPI*

RAM *Random-Access Memory*

RISC-V *Reduced Instruction Set Computers architecture*

RMS *Root Mean Square*

ROM *Read-only Memory*

SELFOC® *Self-focusing Micro Optics*

SME *Small and medium-sized enterprises*

SoC *System on a Chip*

SPAD *Single-Photon Avalanche Diode*

SPI *Serial Peripheral Interface*

SQL *Structured Query Language*

SVD *Singular Value Decomposition*

TPU *Tensor Processing Unit*

WORM *Write-Once Read-Many*

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IMMS Institut für Mikroelektronik- und Mechatronik-Systeme gemeinnützige GmbH (IMMS GmbH)[1]
Ehrenbergstraße 27
98693 Ilmenau,
Germany
+49.3677.87493.00 *Phone*
+49.3677.87493.15 *Fax*
imms@imms.de
www.imms.de
www.imms.de/imprint

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Univ.-Prof. Dr.-Ing. Ralf Sommer,
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