Fraunhofer IPK

Fraunhofer Institute for Production Systems and Design Technology IPK

Research and Development Trends 2022 / 2023

Digitally Integrated Production

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2022 / 2023

Digitally Integrated Production

We Are Looking Ahead.

We are experiencing a time of profound upheaval. After companies in all economic sectors had to radically change their processes in a very short time due to the pandemic, the next challenges follow in the wake of material shortages and energy worries. In addition, factors such as climate change and the shortage of skilled workers are weighing on industry.

At Fraunhofer IPK, we are a strong and proactive partner to our industrial clients in these times. Highly motivated and with innovative approaches, we find creative answers to urgent questions of our customers. In doing so, we benefit from the fact that we combine production expertise with strong digital competency. Digitally integrated production, our vision for integrating highly efficient manufacturing solutions with digital technologies, becomes a reality with our support for SMEs and large corporations alike.

With this issue of »Research and Development Trends«, we emphasize our mission as an R&D service provider with a view to the future needs of industry. The publication's central idea is to focus on the tasks that lie ahead. It is based on an intensive exchange with managers from various sectors in the manufacturing industry: In background discussions, they shared with us their assessment of the state of technical and methodological development as well as upcoming tasks in their respective sectors.

Some of the trends on which everyone agrees: Industrial manufacturing generates a growing amount of data, which – evaluated and put into context in a targeted manner – enables extremely flexible reorganization of production. High-performance machines support efficiency and sustainability in equal measure. And context-sensitive assistance systems use artificial intelligence to support the workforce in all corporate areas according to the situation.

We are looking forward to tackling these and many other issues with our partners in 2022 and 2023. We invite you to join us as we do so.

PROF. DR. H. C. DR.-ING. ECKART UHLMANN
Director

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Quo Vadis, Production?

What challenges and needs will manufacturing companies be facing in the next few years? We asked our industry partners. The result: Technologies for five topics dominated the discussions across all industries. They will have top priority for us in the coming years.

Production 2022 / 2023

Successful Production in a Volatile Environment

If there were an initiative to choose the production word of the year, the current winner would probably be: adaptability. Flexibility combined with a high level of resilience is increasingly becoming a basic requirement for economic existence for manufacturing companies. Without it, not only crisis situations but also everyday customer expectations can hardly be managed. In this context, digitalization and networking are becoming indispensable keys to success.

Volatility is the hallmark of our time. While at the beginning of 2020 it was still believed that the greatest transformation task for the manufacturing industry in the coming years would result from climate change, since then a series of international crises have called decades of production certainties into question. Established supply chains are tottering, sales markets and location conditions are changing radically. At the same time, companies are struggling with long-known difficulties such as the growing shortage of skilled workers and fierce international competition, which are exacerbating cost and time pressures. All these factors are forcing industry to rethink its methods, processes and technologies.

Several close industrial partners of our institute have taken the time to share their assessments of methodological and technological innovation challenges in the manufacturing sector with us. We will address this need at Fraunhofer IPK together with our partners in the coming years.

Production world in upheaval

The challenges that require innovative solutions are manifold. Material shortages, a symptom of the COVID 19 crisis, could become a permanent issue. High energy costs have long been a problem, especially in Germany. The global political situation put them at the top of the agenda in business in early 2022. In addition, regulatory requirements have come up, in the interests of safety standards or to combat climate change, but also in the context of regionalization efforts and autocracies. Last but not least, demographic change and the resulting threat of a loss of knowledge are putting a strain on companies.

At the same time, customer expectations and the goals that companies set themselves are changing. Individualized customer needs are leading to highly differentiated product portfolios, in some cases down to batch size 1. Such dynamics call for flexibility – and recipes for success that will attract imitators. Staying one step ahead of the competition is becoming a matter of existence. As a result, companies are not only looking at solutions for agility, but also at the following questions, among others: How can we operate and maintain similar machine parks at globally distributed locations? How do we guarantee the same quality at these locations with differently skilled workers? How do we protect our know-how? And how do we become sustainable in all of this?

Digitally integrated production increases competitiveness

More and more companies are tackling these challenges with digital methods. This way, a concept is arriving in practice that has been postulated as Industry 4.0 and that we at Fraunhofer IPK call digitally integrated production: A production world is emerging in which all the resources involved – people as well as individual or networked systems – collect data, communicate their status and coordinate tasks interactively. This supports flexibility and makes the associated complexity manageable. Companies adapt to constantly changing requirements with foresight. Consistent quality can be more reliably assured as mechanical manufacturing companies transform into high-tech enterprises.

»Digitization and the application of artificial intelligence characterize a contemporary high-tech group. SCHOTT is consistently pursuing this path.«

Volker Trinks, SCHOTT

In the »RESYST« white paper,
we explain how companies can position themselves to withstand crises.
↪ www.ipk.fraunhofer.de/resyst-en

From the discussions with our partners, we have derived five priority topics that concern companies across all industries and on which we will focus our research in the coming years:

- Data management, networking and analysis
- Manufacturing systems and production control
- Intelligent mechatronic systems technology
- Knowledge and assistance in production
- Sustainability and environmental compatibility

With concepts, technologies and solutions for these areas, we want to help increase the competitiveness of our customers and partners. With our current research and development projects, we are excellently prepared to do just this. The highlight activities we present in this Yearbook underline our proximity to the solutions that are currently reaching and changing industry, and to the innovation tasks that companies will face next.

Talking about Production

The following experts have shared their assessments of the development status in industry with us. We sincerely thank them for the discussions!


© Bosch

Sven Hamann

CEO,
Bosch Connected Industry


© BIOTRONIK

Dr.-Ing. Christoph Hübert

Senior Director Development Leads,
BIOTRONIK SE & Co. KG


© Ulrike Packi / Infographics

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Vice President International Production BMW Motorrad,
BMW Group


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Dr.-Ing. Anne-Katrin Tomys-Brummerloh

Manager Production Planning Trucks Assembly,
Daimler Truck AG


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Dr.-Ing. Volker Trinks

Vice President Technology Tubing,
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Data Management, Networking and Analysis

Zeros and Ones at the Factory

No matter who you talk to in the industrial environment, everyone speaks about the challenge of capturing data and storing it appropriately, transmitting it securely and analyzing it intelligently. Behind all this is the goal of using data-driven solutions to make processes more efficient or to generate new business models. But how is this supposed to work?

Our solutions for this topic area

- **IIoT architectures** that extract meaningful data from raw data
- **Cloud and edge technologies** for application in production
- **Data continuity** based on PDM, PLM and other technologies
- **Digital twins** for all business units and technology levels
- **Enterprise cockpits** that merge data across domains

There was a time when machine tools were closed systems. It is true that since the 1960s they have increasingly been equipped with digital controls, which, in addition to the automatic control of states and movements, facilitated the setup of machining processes and to a certain extent also enabled them to be monitored. However, comprehensive condition monitoring or even connecting a machine to a cross-company production control level would not have been possible on this basis. This has changed when the idea of »Industry 4.0« emerged: Today, wireless units in machine tools provide network capability, and sensors transmit a wide variety of operating data. But what is the point of all this?

From selective monitoring to the 360° digital twin

The basic idea: By evaluating sensor data, machine behavior can be monitored or machining processes can be optimally adjusted. Via wireless technology, a machine signals to production management that it is ready for the next job. And that is only a fraction of the possibilities. The picture becomes more comprehensive with a so-called digital twin. The virtual image of a process or machine reflects their geometry and structure as well as their behavior. Imagine if all process levels in a company, from product development and purchasing to production and assembly, sales and marketing, were underpinned by such systems. If these were also linked across disciplines, the result would be a 360° twin, a highly integrated corporate image, that can help bring a previously unattainable degree of efficiency to value creation.

This is no longer a pipe dream. Digital twins have reached application maturity, are in demand by industry and are being made fit for various sectors and areas of application at our institute, among others. In the »Mastering Digital Twins« certificate program, we provide background knowledge that enables companies to put digital twins to use.

»Our greatest progress in recent years has been to actively use data from our plants to analyze processes, describe our company performance or underpin decisions regarding new technologies,« says Dr. Christoph Hübert, Senior Director Development Leads at medical device manufacturer BIOTRONIK SE & Co. KG. But very few have advanced that far. Even established companies in the manufacturing industry are still in the early stages of using data intelligently.

Collecting suitable data sets with IIoT platforms

That's not surprising, either, because the challenges start two steps earlier. »At the moment, some consulting companies are conveying that all you have to do is integrate plenty of sensors into machines and stream masses of data into a cloud, and then you would have Industry 4.0,« criticizes Dr. Ansgar Kriwet, member of the management board sales at Festo SE & Co. KG and member of the Fraunhofer IPK Board of Trustees. »But nobody gets anything out of that.« Rather, he says, the first step at the beginning of digitizing production should be to analyze which data make sense for the company-specific use case, because they enable added value. Often, this data can already be accessed through existing sensors. We are addressing this question in a series of research projects with CONTACT Software GmbH on the topic of Industrial

»The goal is not to have masses of sensors flush as much data as possible into clouds. It has to be the right data.«

Ansgar Kriwet, Festo

Information about the »Mastering Digital Twins« program can be found ↪ on page 67.

Internet of Things (IIoT) platforms. The goal is to move from big data to smart data in order to make data volumes manageable and to collect precisely the data that is of value to the respective company.

And the collaboration with CONTACT goes even further: How can large volumes of data be securely transferred, stored and retrieved? »Integrating machines into a network requires an IT infrastructure that many companies don't even have,« reports Martin Kapp from the KAPP NILES group and another member of our board of trustees. Cloud and edge technologies can be a solution here. The complex interplay of data ecosystem, infrastructure and services is addressed, among other things, in the European cloud project »GAIA-X«, in which researchers from our institute are participating. Data security and data sovereignty are also being addressed, because: »The acceptance of distributed solutions presupposes that these issues are resolved,« as Sven Hamann, CEO of Bosch Connected Industry, notes.

Product data management throughout the lifecycle

A final intermediate step before data utilization is data consistency. The goal must be to pass data from early lifecycle phases of a product through the production process to application. Ideally, usage data should flow from the last point in the chain into optimization loops. Such comprehensive Product Lifecycle Management (PLM) has been an important research topic at our institute for years. In the »Mastering PLM« training course, we also provide hands-on training for product data management specialists. The next logical step in data handling must then be to link PLM with process control right down to the shop floor, so that design data, for example, can be used to set up manufacturing processes without any detours.

»But the really big leap would be to include data from supplier companies in the overall view of the company's own data network,« says Dr. Hübert, formulating the next challenge. »That would simplify certifications and quality controls enormously.« Looking into the data environment of companies is still difficult to realize. But there are promising approaches. With the situational awareness cockpit, we offer a tool with which companies can link environment information with internal capabilities. In this way, alternative courses of action can be developed quickly if, for example, a supply chain breaks down.

Data-based value creation increases profitability

Efficient data handling and intelligent data use take value creation to a new level. Processes can be simplified and accelerated, for example with artificial intelligence (AI) and machine learning. Intelligent process control is becoming a reality, as are adaptive assistance systems that support the handling of variants, quality assurance or the maintenance of machinery. Completely new business models are even emerging, such as service offerings based on data from machines.

Note the first highlight
↪ on page 18.

»Collecting data is the mandatory program. But data-based value creation only begins when I – based on this – improve processes.«

Patrick Müller, CONTACT

Information about the »Mastering PLM« training course can be found
↪ on page 67.

Situational awareness cockpit
↪ www.ipk.fraunhofer.de/situational-awareness-cockpit

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Realizing Continuous Data Flows

Dr.-Ing. Patrick Müller

Dr.-Ing. Patrick Müller
CONTACT Software GmbH

studied and earned his doctorate at the Technische Universität Berlin and then worked at Fraunhofer IPK. From there, he joined CONTACT as a product manager in the fields of PLM and IoT. He is currently a member of the management board, active in strategic tasks. He is also a founding member of the CONTACT Research unit.

In recent years, CONTACT Software has been transforming from a PLM professional to an IoT provider. Why is that?
We started with data and process management in the area of product development. But new methods of handling and linking data – including AI – now make it sensible to look further: How can data from the product creation phase be transmitted directly to production? How do I need to couple production steps with my logistics concept and the handling of the order, i.e. from an information logistics perspective? How can user feedback be fed back into product optimization? With new digital technologies, you achieve data consistency that generates added value for the process landscape in companies. The willingness to tackle such topics has increased massively in industry.

How far have companies come in terms of data consistency?
Less far than one would expect. Production has been getting tidier for years, a lot is being automated. In contrast, there is a lot of catching up to do in the area of end-to-end data flows. There are various reasons for this. For example, there are many IoT platforms, but almost all of them serve a limited field of application. This makes it difficult to establish connectivity in order to bring together data from all relevant areas of the company in the sense of integrated applications, for example cockpits. In order to optimally support batch size 1 in terms of information technology, the first step is to harmonize information levels. Together with Fraunhofer IPK, we are developing technologies that aim to do just that.

But do production companies know what they get out of it?
Yes, they do. A few years ago, they didn't really know: What is a digital twin in my application area? What does digital thread mean to me? What does it even mean in terms of technology? Now there is a much clearer picture. There are technological answers, and with that comes a willingness to act on them. Now we have to take all these things to the next level and work together in the supply networks for the circular economy and an Industry 5.0.

The CONTACT Elements platform can be used for digital data and process management in the areas of PLM and IoT and supports central company processes. For this purpose, it offers a so-called composable architecture according to Gartner, which can be individually assembled for company-specific use cases.

R&D Highlights on Data Management, Networking and Analysis

Our selected activities on data handling and application show how we bring data-based AI into production: with digital twins, optical identification of components and fault prediction via process data.

01

CREATING ADDED VALUE WITH DIGITAL TWINS

Research and development cooperation agreement for Industry 4.0 solutions
For around ten years, the term Industry 4.0 has described a production that is fully networked in all areas by the Industrial Internet of Things (IIoT). However, although 95 percent of German companies now see the concept as an opportunity, 66 percent still have difficulties in implementing it. IIoT platforms are an essential prerequisite for efficiently collecting and evaluating manufacturing data and using it in digital twins – the basis for Industry 4.0 applications. To help companies get started with networked production, we have entered into a strategic partnership with CONTACT Software GmbH to jointly develop concepts, scenarios, show cases and specific prototypes around the use of digital twins for Industry 4.0.

Partner:
CONTACT Software GmbH

02

INFORMATION CONCEPT FOR DEVELOPING HYBRID-ELECTRIC DRIVES

Development and testing of integrated and networked value-added processes and integrated manufacturing concepts as a basis for resource-efficient flying using hybrid-electric drives with the goal of European technology leadership
An example of what can be achieved with digital twins: Making air travel more climate-friendly. There are numerous challenges to be overcome in the development of electric or hybrid-electric drives. These include storing and providing electrical energy efficiently or integrating appropriate battery systems. In order to efficiently implement the new drive concept, our researchers have developed a cross-lifecycle information concept for aircraft construction. It digitally networks all value-added steps to facilitate a deeper understanding of system dependencies, particularly at the interfaces of different functions.

Partners:
- 7 Fraunhofer Institutes
- Rolls-Royce Germany

Funding notice:
Fraunhofer-Gesellschaft

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03

AUTOMATIC IDENTIFICATION AND EVALUATION OF OLD PARTS

EIBA: Sensor-based detection, automated identification and evaluation of used parts based on product data as well as information about previous deliveries
Data- and AI-based adaptive assistance systems can support a wide variety of tasks in production. For example, the reuse of used parts: Not every used component is »ready for the garbage can.« Many can be reused – provided they are reliably identified. But many product models differ only slightly or are difficult to identify due to rust, dirt or missing parts. We have developed a technology that uses AI to identify objects, regardless of condition or markers. The AI learns with each application. It can automatically adapt to new objects and changing environmental conditions and improves continuously.

Partners:
- acatech – National Academy of Science and Engineering
- Circular Economy Solutions GmbH
- TU Berlin, Handling and Assembly Technology chair

Funding notice:
The project is funded by the German Federal Ministry of Education and Research (BMBF) under the »Resource-efficient Circular Economy – Innovative Product Cycles (ReziProK)« funding program with the funding code 033R226.

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FONA Resource Efficiency
BMBF

ReziProK
Resource-efficient Circular Economy – Innovative Product Cycles

04

DETECTING WELDING DEFECTS VIA PROCESS DATA

Currently, it is hardly possible to inspect weld seams in large series without destroying the result. At the same time, the variety of sensors used in welding processes is increasing. Possibilities for data output to welding systems are also expanding continuously. However, a single data source usually doesn't provide a sufficient conclusion about the result. We develop methods that evaluate data from several sensors in conjunction. This enables reliable testing of the welding process, a prerequisite even for countermeasures in the event of deviations such as spatter or pore formation.

Manufacturing Systems and Production Control

Manufacturing without Takt and Assembly Line

The most important argument for data-driven, networked manufacturing lies in its potential to bring flexibility to production. For a long time, there was no alternative to rigid production structures when fast throughput was required. Now they are becoming obsolete. Instead of highly integrated, firmly linked lines, manufacturing experts increasingly favor modular production systems that can be flexibly combined.

Our solutions for this topic area

- **Agile process management** for flexible production organization
- **Virtual and physical adapters and sensors** for networking
- **Modular shop floor IT** for synchronization of heterogeneous production systems
- **Intra-process logistics** with driverless transport systems
- **Partially autonomous process chains** up to self-organizing production
- **Virtual commissioning** with digital process, factory and machine twins

The efficiency of serial processes and firmly linked production lines is undisputed. If one process step reliably follows the next, orders are processed in a short period of time. But rigid production structures also have disadvantages. The biggest is that it is costly or even impossible to realize customer-specific special orders. However, these have long been part of everyday life in many companies, even in the classic series production business. Some suppliers operate with 50,000 system products at annual repeat rates of 1.4.

So much need for agility makes highly integrated systems uneconomical. »High integration is the opposite of agile. Reprogramming integrated systems for customers who need special features is far too time-consuming and expensive,« sums up Dr. Hübert of BIOTRONIK. He is not alone in this assessment. Companies that manufacture a large proportion of their products only once carry out many process steps by hand. Extensive automation is not worthwhile for them; instead, they favor smaller, highly flexible systems technology.

Networking makes the factory of the future highly flexible

Machine builders and system suppliers are now responding to this demand. »Imagine a factory in which only the floor and ceiling are fixed, the rest is flexible,« says Sven Hamann of Bosch, outlining the factory of the future. »In such a factory there are robots, mobile equipment, manual workstations with operator guidance or reusable standard machines. I can rearrange and reconfigure all of this in a very short time.« In such a production environment, machines are product-agnostic: The same equipment is used to produce different variants of a product – or different products.

In the flexible factory, the network hub becomes as essential a machine component as the chuck, because production steps are interlinked by information technology. This is a major task since it involves bringing systems into dialog that originate from different manufacturers or use heterogeneous standards. One option among others to achieve this is using IT adapters to open up the machine control system for networking. Ideally, the result is a self-organizing production as is being promoted by Fraunhofer IPK. Here, all manufacturing entities – people, workpieces, machines and tools – communicate and cooperate directly with each other. For example, a workpiece can independently organize its path through production by requesting suitable machining resources. Machining stations offer free capacities or reject them, if their data indicates a need for maintenance.

Level of automation can vary

The level of automation can vary widely from one company to another. Therefore, there is no universal answer to the question of what Industry 4.0 looks like. Some companies benefit most from digitally supported process control. In the simplest case, such process control can just pass on knowledge from one station to the next – about the type of order, which components belong to it and how they are to be processed in the next step. More autonomous process controls address equipment directly to orchestrate processes. With model-based, modular concepts process steps can be combined into ever new sequences. This makes production variable and customer-specific production

Agile process management
is investigated in the »MAP« project
↪ www.ipk.fraunhofer.de/map-en

»In the factory of the future, everything is flexible, can be rearranged and reconfigured in a very short time.«

Sven Hamann, Bosch Connected Industry

»Our production facilities are becoming more product-agnostic. No matter what the product looks like, they have to produce it.«

Christoph Hübert, BIOTRONIK

Modular Shop Floor IT
↪ www.ipk.fraunhofer.de/msfit-en

or quick reactions to exceptional situations effortless. Last but not least, resilience in the face of crisis situations ist fostered.

For some companies, it will still be worthwhile to fully automate certain parts of their processes. Picking, machine loading or even tool changes are particularly suitable. With AI-based methods of optical recognition, they can be designed efficiently even when product blanks or tool types continuously change.

In the »PoWer« project, for example, an automated replacement system for indexable inserts is being developed
↳ www.ipk.fraunhofer.de/power-en

Integrating logistics solutions into process management

Comprehensive automated solutions are also a very good option in intra-process logistics. This is an area that has long been a marginal topic in manufacturing theory. »Up to now, in-process logistics has not generally been understood as part of value creation, but this way of thinking is no longer up to date,« says Prof. Helmut-Joseph Schramm, Vice President International Production BMW Motorrad and a member of our Board of Trustees. After all, anyone who abandons takt and assembly lines needs alternative solutions to ensure that the product gets from A to B in the production process and that the required material is available at every processing station.

This is where driverless transport systems (AGVs) or automated guided vehicles (AGVs) come into play. They can even be integrated into the process control system – logistics becomes an integral part of the production process. Daimler Truck AG is applying this concept. »In some of our plants, vehicle cabs no longer travel on the assembly line, but on AGVs from one processing station to the next,« reports Dr. Anne-Katrin Tomys-Brummerloh, manager of assembly planning and implementation of innovative technology at Daimler Truck. »The AGV carries the information about which production number it is currently running. When it enters a station, the work order is retrieved there.«

»In flexible production, logistics is an important cross-sectional function.«

Helmut-Joseph Schramm, BMW Group

Manufacturing engineers' toolbox of methods expands

If production lines and other shop floor equipment are flexibly plugged into ever-new processes, the methods and technologies for piloting and validation should also change. Digital twins and virtual commissioning play a crucial role here. They can be used to check whether each machine fits in its intended place when it is rearranged and whether the arrangement makes sense. If a process is reconfigured, it can be ensured that it will run smoothly. This keeps downtime during commissioning and reconfiguration to a minimum.

All these new ideas are changing the view of what »the production process« encompasses and how it should be designed. Interaction with IT and logistics expands the range of tasks in system design. Experts from different domains must work together much more closely than before. At Fraunhofer IPK, this is already reality. In addition, it is to be expected that in the future digital technologies will become domain tools of production technology just like logistics solutions.

R&D TRENDS 2022 / 2023 | Manufacturing Systems and Production Control

Thinking about Flexible Production Processes Holistically

Q&A

Prof. Dr.-Ing. Helmut-Joseph Schramm


© BMW Group

What motivates you to make production processes at BMW Motorrad more flexible?
We have the largest number of variants in the motorcycle industry. Individuality is virtually a trademark of BMW Motorrad. No two bikes are alike; every customer can put together his or her own individual motorcycle. At the BMW Group plant in Berlin, we work with around 11,000 living part numbers – the resulting complexity can only be handled with intelligent solutions. Flexibility is also a crucial tool for increasing resilience. Our flexible production system makes us successful as a team even in times of high volatility.

What kind of intelligent solutions are you thinking of?
The range of possibilities extends from intelligent solutions for realizing customized designs within the series production process to networking production processes using artificial intelligence methods. One example from so-called smart logistics is intelligent robots that facilitate the production process. Such as »Sortbot«. It autonomously sorts around 5,000 empty containers a day, stacks them and makes them available to logistics for collection. In the process, the robot is able to identify various container shapes and types using a 3D camera and sort them onto the correct pallet using artificial intelligence. It is important that we always look at the entire production process.

What do you mean by that?
The so-called intra-process logistics play a very decisive role. What I see is that in production, logistics between processing steps is often neglected. However, it is an important cross-sectional function: If production processes fail, it is usually not due to individual production steps, such as machining, but because coordination from one process step to the next doesn't work – for example, if material is missing in the next processing step. That's why we won't get to self-optimizing systems without smart logistics.

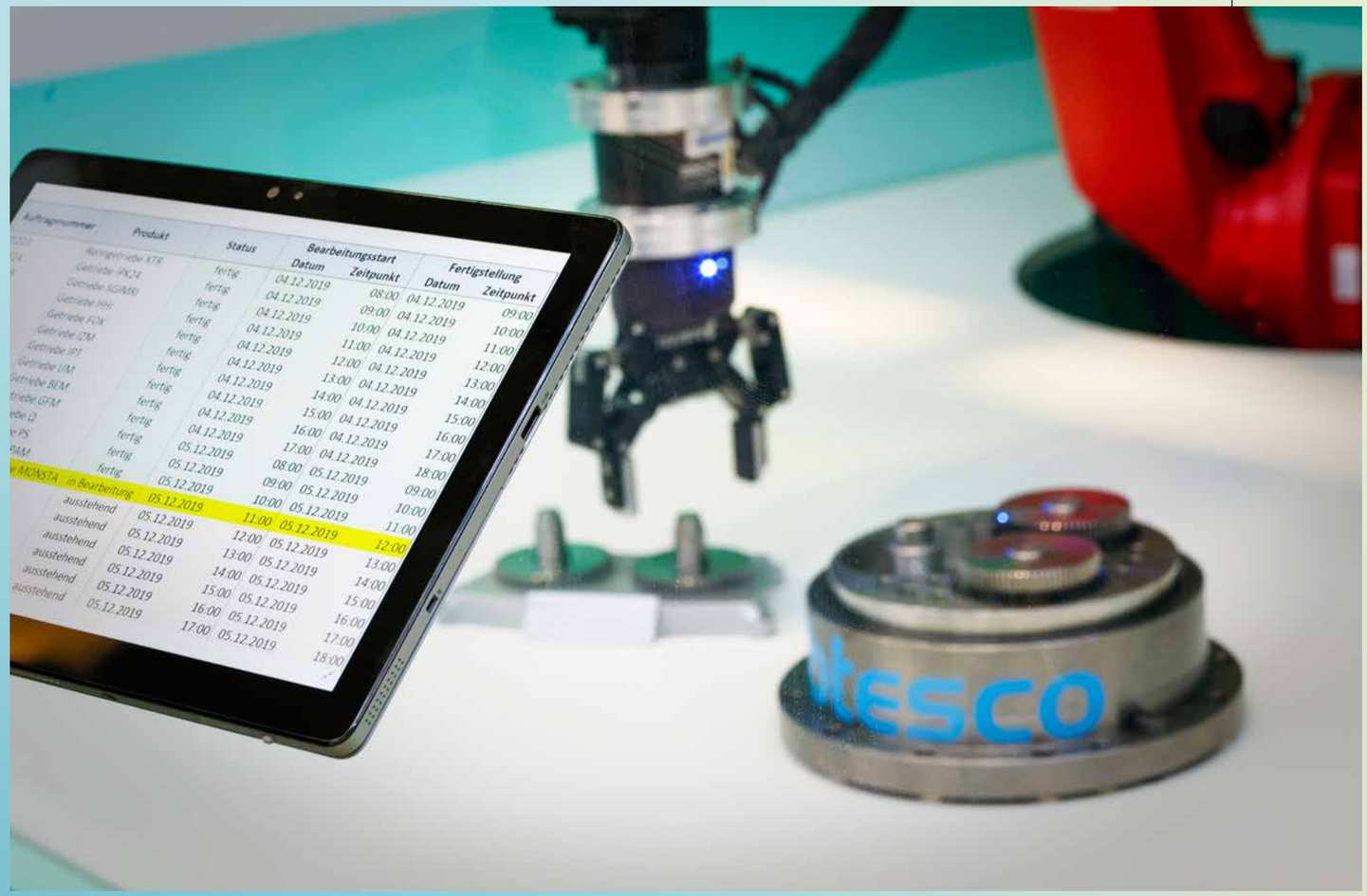
Prof. Dr.-Ing. Helmut-Joseph Schramm
BMW Group

has since 2017 been managing the global production of BMW Motorrad as well as the BMW motorcycle plant in Berlin-Spandau. Since 2004, he has also been an honorary professor in logistics and production management at the Technical University of Applied Sciences Wildau.

The BMW Motorrad plant in Berlin is the flagship unit, i.e., the leading plant in the BMW Motorrad production network. Here, motorcycles are produced and exported to over 130 countries. Supported by Fraunhofer IPK, BMW Motorrad is developing a technology that integrates customized design into a series production process.

R&D Highlights on Manufacturing Systems and Production Control

Our references from the topic area of manufacturing systems and production control show how we make processes more autonomous and which solutions we develop for their piloting and commissioning.



01 SETTING UP ASSEMBLY LINES FASTER WITH DIGITAL TWINS

Robot-based pilot system for validating complex automation processes

Automating assembly lines costs companies a lot of money and time. A large part of this expenditure goes into pilot systems, on which automated processes are developed and carefully tested. This is because errors in the design of an automated process often result in considerable additional expense. We have developed a pilot system on which interlinked production systems can be developed cost-effectively and complex processes can be tested reliably with the aid of a digital twin – at comparatively low investment costs. The time required for setup and reconfiguration is reduced to one third.

02 AUTONOMOUS MANUFACTURING OF ELECTRIC DRIVES FOR INDUSTRIAL APPLICATIONS

Electric drives: Research project »Change in production technology«, Werner-von-Siemens Centre for Industry and Science (WvSC)

How can electric drives for metal industry, mining or energy, oil and gas industries be manufactured competitively while conserving resources? Digitalization offers enormous opportunities here. In cooperation with the Werner-von-Siemens Centre, we are implementing end-to-end digitalized and automated production chains that ensure rapid commissioning of electrical machines. We also provide methods and technologies for electrical machines: We design digital twins to design and manufacture electrical drive components, develop new technologies for their additive manufacturing and define processes for predictive maintenance and repair.

Selected partners:

- Bundesanstalt für Materialforschung und -prüfung (BAM)
- Siemens AG
- Technische Universität Berlin

Funding notice:
This project is co-financed by the European Regional Development Fund (ERDF).

EUROPEAN UNION
European Regional Development Fund

03

TRAININGS IN VIRTUAL REALITY BASED ON VIRTUAL COMMISSIONING

VR-based development tools for virtual commissioning

When integrating new robot systems into a production environment, the behavior and path are elaborately adapted to the spatial situation at the site. If this is done physically on-site, valuable time is lost during which the robot is not available for productive operation. It is more economical to perform large parts of the setup using intuitive virtual reality methods. Our researchers have developed a software architecture that enables fully immersive virtual commissioning of robot kinematics, including collision analysis. Digital twins take into account the real system state. This increases accuracy of the simulation and reduces development times. With ViCom-GameTrain, an extended reality-based training environment, maintenance personnel can additionally be trained quickly and cost-effectively to work with the systems.

Partners:

- Baby Giant Hollyberg GmbH
- BenThor automation s.r.o.

Funding notice:
The project is funded by the German Federal Ministry of Education and Research (BMBF).

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04

AUTOMATED MACHINE LOADING WITH MOBILE ROBOTS

Tend-O-Bot

Bringing flexibility in factory control from the control level to the shop floor requires new solutions for automated handling and transport systems. Previously available systems require rigid and carefully structured environments for applying robotic solutions. Therefore, we are developing algorithms that extend the sensory and cognitive capabilities of robotic systems. Thus, the combination of these algorithms opens up new applications, such as combining a lightweight industrial robot with an autonomous transport (AMR) system for automated and fast machine loading. The system also enables automatic handling of different workpieces up to previously unknown objects without manual and job-specific programming of the robot.

Funding notice:
Fraunhofer-Gesellschaft

Intelligent Mechatronic Systems Technology

When the Machine Reports Its Status

Even if the central concern of digitally integrated production or Industry 4.0 is networking industrial systems – the individual machine remains a central focus point of optimization. The reasons: Networking requires interfaces that must first be implemented on the individual machine. Also, topics such as resource efficiency are continuously addressed with development at the machine level.

Our solutions for this topic area

- **Sensor technology for machines** as original equipment or for retrofitting
- **Machining strategies and technologies** for new materials
- **Force-controlled and manually guided robotics** for processing and handling
- **Innovative manufacturing methods** such as additive manufacturing or injection molding with metallic materials
- **Sensor integration** in additively manufactured components

Networked processes are based on data from individual systems. Machines – whether machine tools or robots – are being given more and more digital functions. There are several reasons for this. »Flexibility plays a role,« explains Festo's Dr. Kriwet. »Users want to be able to retool systems more quickly. Therefore, many machine builders increasingly prefer to use electric instead of pneumatic drive technology, because you can approach intermediate positions with it.« In addition, since electric drive technology can control motion dynamics more precisely than pneumatic technology, it also achieves higher-quality results.

Above all, however, integration of electronics makes it possible to continuously monitor the status and behavior of systems and to map them in digital system twins. This way, production and environmental influences can be detected and corrected, and adjustments can be simulated in advance. This allows processes to be set up more efficiently than ever before. In addition, it is possible to intervene at an early stage, if a process is not running smoothly or if machine damage is imminent.

Sensors monitor machines and support their control

Sensors and network technologies integrated into machines are the basis needed for such functions. These components are becoming ever cheaper. »In the past, mechanical systems cost 100 euros and certain electronic or sensor equipment 200,« reports Dr. Kriwet. »Today mechanics still cost 100, but sensors and electronics only cost two euros. Now it makes sense to upgrade mechanics with a lot more electronics, sensors and communication technology.«

The benefit is accurate monitoring of parameters such as temperatures, vibrations and energy consumption. Machine learning and artificial intelligence algorithms can learn from such data, for example, what the »normal state« of a machine looks like – and warn when deviations from the target occur or problematic trends emerge. As a consequence, smart and predictive maintenance can be carried out before a machine breaks down. This facilitates completely new maintenance concepts.

But also setting up machining processes and running them as best as possible benefits massively from intelligent data analysis based on sensor technology. »Analysis systems can reveal unrecognized potential for improvement in processes. In tests, suggested parameter changes have reached the quality of expert recommendations, and in some cases even exceeded them,« reports Dr. Volker Trinks, Vice President Technology and Tubing Development at SCHOTT AG. Scarce or expensive resources such as energy can thus be used more economically and efficiently than before. And there is another aspect to be considered: When machines optimize their processes to a certain extent autonomously with the help of AI, quality is achieved with greater consistency. In addition, know-how can be transferred easily and securely to different locations, if it is encapsulated as an automated process within a system.

Hardware for digital functions must be durable

A prerequisite is careful selection of electronic components, because it is a problem for mechanical engineering that development cycles in the electronics

»With the use of our AI solutions in the plants, we achieve savings of several million euros.«

Sven Hamann,
Bosch Connected Industry

sector are becoming shorter and shorter. Many electronic devices are developed with mass markets in mind, which want fast system changes in the interest of ever greater performance and capacity. Mechanical engineering needs greater consistency. Some companies now have enormous difficulties finding components that are available even for five years. This places immense demands on the flexibility of software and development.

The danger of an expensive machine tool coming to a standstill, because a three-euro sensor fails or control software can no longer be updated, is also seen at KAPP NILES and Festo. From the point of view of the machine manufacturers, the goal must therefore be to find a good balance between the added value that can be achieved through digitalization and the associated expense and risk. Against this background, it is conceivable to keep electronic components in machines interchangeable. Retrofitting is also a viable option.

Manufacturing processes for new materials and components

However, there is also optimization potential in the field of machines beyond electronic upgrading. Machining strategies for new, sustainable materials are just as much a concern for companies as are primary shaping processes that can be used, for example, to easily integrate components made of different materials. One topic here is primary shaping with metallic materials around components produced by other manufacturing methods. Injection molding is just as much a possibility as additive manufacturing.

In the automotive sector in particular, there is a great need for R&D in the context of new drive concepts, shorter product cycles and new, environmentally friendly high-performance materials. »Just one example: e-mobility requires a different grinding technology, because finer surface structures are needed,« reports Martin Kapp from KAPP NILES. At Fraunhofer IPK, we develop technologies for high-performance machining that meet the highest requirements for productivity, reliability and resource efficiency.

New control methods make robotics universally applicable

When it comes to setting up manufacturing environments in such a way that they can be flexibly adapted to new tasks at any time, systems technology beyond the classic machine tool also becomes interesting. The robotics market, for example, expects double-digit growth rates in 2022, as the German Mechanical Engineering Industry Association VDMA reported earlier this year. Robots have »learned« a lot in recent years: Thanks to modern force control and new solutions for human-robot cooperation, they have evolved into universal and even mobile processing and assembly machines.

Robots become particularly flexible when humans can safely work with them in a confined space. Then the path guidance does not have to be programmed down to the last millimeter. Humans can fine-tune the robot movement manually. Against this background, BMW's Prof. Schramm sums up: »I am convinced that the further expansion of smart interaction between humans and robots will shape the future.« New concepts for programming, for example based on gestures, also facilitate rapid setup.

»We see a strong trend to complement classic robotics with stationary and mobile HRC robots.«

Holger Klempnow,
KleRo Roboterautomation

Read more at
↳ www.ipk.fraunhofer.de/production-processes

Q&A

Technologies and Equipment for Digitally Integrated Production

Prof. Dr. h. c. Dr.-Ing. Eckart Uhlmann

Prof. Dr. h. c. Dr.-Ing. Eckart Uhlmann
Fraunhofer IPK

is head of Fraunhofer IPK and of the Machine Tools and Manufacturing Technology chair at Technische Universität Berlin. His research focuses on the development and optimization of machine tools and production systems as well as on increasing the performance and resource efficiency of manufacturing processes.

How much emphasis does Industry 4.0 place on optimizing production systems?

At Fraunhofer IPK, we prefer to use the term »digitally integrated production« instead of »Industry 4.0«, to make it clear that production is the main focus. We see digitalization as a tool to support processes – including the actual manufacturing processes. Nevertheless, it will remain necessary to put engineering know-how into these manufacturing processes and thus, also into the equipment on which they run in order to optimize them.

Which are the development needs in this area?

Our time is characterized by disruptive changes that require new ways of thinking in production. New, environmentally friendly materials and manufacturing processes need to be developed. Aspects such as zero-emission and zero-defect production are also coming to the fore. This cannot be done without suitably adapted equipment.

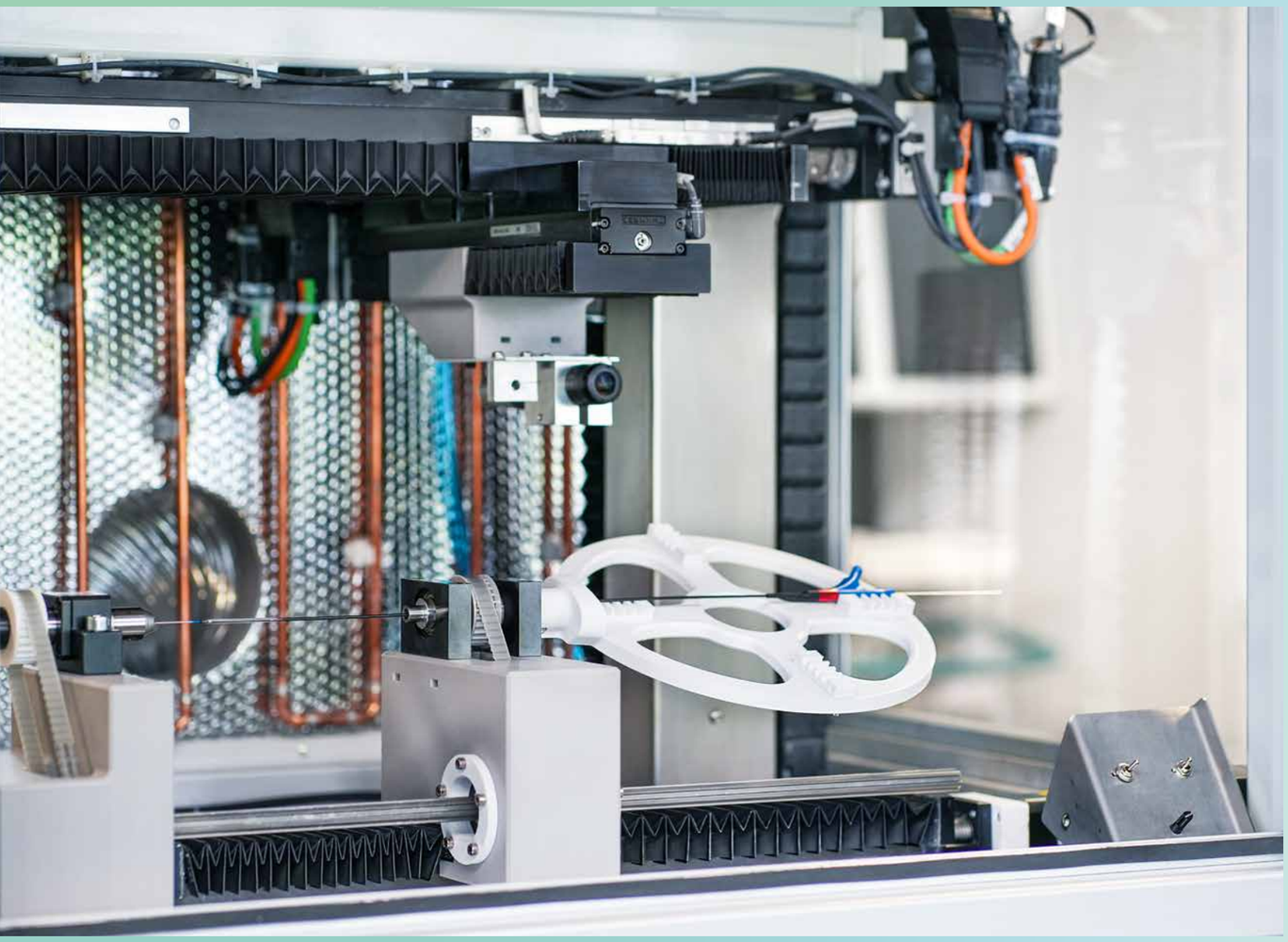
How does »digitally integrated production« affect systems manufacturers?

Production systems must become intelligent, independently monitor and optimize their processes, and communicate with their environment. In short, they must develop into cyberphysical systems. In addition to software, this also requires sensors and actuators integrated into the machines. Systems manufacturers who have so far focused on the actual manufacturing process must expand their competencies in this area or enter into strategic partnerships with corresponding know-how providers.

Share of industry in gross national product	28 %
Employees in manufacturing companies in Germany	5.5 million
Engineers in Germany	660,000
Germany's level of digitalization in EU comparison	11th place
Growth rate of the sensor industry (2021)	+20 %

R&D Highlights on Intelligent Mechatronic Systems Technology

Intelligent production systems are one of Fraunhofer IPK's core business areas. Our highlights are new developments for application in medicine, lightweight construction in the automotive sector and additive manufacturing.



01

NEW MACHINE FOR COATING BALLOON CATHETERS

Heliko: Automated and reliable coating of balloon catheters
Constrictions in the coronary arteries caused by calcium deposits are increasingly being dilated with the aid of balloon catheters. The catheters are coated in advance with drugs that prevent the artery from closing again. Until now, such balloons have been coated manually. Together with partner companies, our scientists are developing a new system that automates this time-consuming process.

Partners:
- InnoRa GmbH
- Organical CAD / CAM GmbH

Funding notice:
The project is funded by the German Federal Ministry of Education and Research (BMBF).

SPONSORED BY THE
Federal Ministry of Education and Research

02

NEW TECHNOLOGIES FOR PRODUCING CFRP COMPONENTS

MAI CompCar: High-performance compression molding and machining of CFRP thick parts for structural applications
To make vehicles more efficient and sustainable, companies in the automotive sector are increasingly looking to reduce their weight. Carbon fiber reinforced polymers (CFRP) promise to make vehicles lighter while still maintaining the necessary component strength. However, CFRP components present automotive companies with technical challenges in terms of cost efficiency and production volumes. In the German-Brazilian »MAI CompCar« project, we therefore join forces with 16 international partners to develop processing technologies for high-performance materials. This includes milling and cooling strategies as well as optical quality control.

Selected partners:
- Composites United Leichtbau-Forschung gGmbH
- Institute for Technological Research of the State of São Paulo
- Maxion Structural Components
- Hufschmied Zerspanungssysteme GmbH
- Solvay Composite Materials

Funding notice:
The IGF project No. 312 EN is funded by the German Federal Ministry for Economic Affairs and Climate Action in the CORNET: Collective Research Networking framework.

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

03

HUMANS AND ROBOTS WORKING CLOSELY TOGETHER

SHERLOCK: Seamless and safe human centered robotic applications for novel collaborative workspaces

For safety reasons, direct human-robot collaboration (HRC) has so far only been possible with lightweight robots. »SHERLOCK« starts where lightweight robots reach their limits: The project is creating design, planning and control methods that enable human-robot collaboration with higher payload robots in larger workspaces. Technologies developed by SHERLOCK include communication via AR / VR systems, recognition of human intentions, and flexible planning algorithms. This allows the robot carrying heavy load to perform coarse positioning, while the human provides only high-level information about which position is targeted and performs fine positioning.

Selected partners:

- University of Patras
- COMAU SPA
- Pilz GmbH & Co. KG
- Fundacion Technalia Research & Innovation
- Light & Shadows

Funding notice:
This project is funded by the European Union's Horizon 2020 research and innovation program under grant number: 820689 – SHERLOCK.

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R&D TRENDS 2022 / 2023 | Intelligent Mechatronic Systems Technology

04

REPAIRING COMPONENTS IN FIVE AUTOMATED STEPS

Automated reverse engineering for defective components

When a systems component breaks, repairing it is often more environmentally friendly than using a new component. Additive technologies are increasingly being used to repair defective parts, including ones made of metallic materials. But the process involves a lot of manual labor. Our scientists have therefore developed an end-to-end repair process chain in which components are digitally captured in five steps and repaired using Directed Energy Deposition (DED) technology. First, a 3D scan of the component is made, in which defective areas or geometries are subsequently recorded. From this, a differential volume is derived, which is a 3D representation of the spot that needs to be filled or otherwise repaired. CAM planning is then carried out for this volume before it is repaired in the final step using DED and final post-processing.

Knowledge and Assistance in Production

Focusing on the Human Being

Even though artificial intelligence and autonomous solutions are increasingly conquering manufacturing, nothing works in production without qualified employees. And these are becoming increasingly hard to recruit against the backdrop of demographic change and a shortage of skilled workers. This makes it all the more important to provide people in production with the best possible support, to transfer their knowledge and to maintain their ability to work for as long as possible.

Our solutions for this topic area

- **Semantic data structures** as a basis for intelligent interpretation
- **Decision preparation** on the basis of automated data evaluation
- **Interactive assistance systems** with context-sensitive user guidance
- **Ergonomic and strength support** with wearable robotics
- **Knowledge and competence management** with effective, systematic solutions
- **Serious games and learning factories** to qualify for digital transformation

With raw material shortages, supply chain problems and climate neutrality, industry is currently facing many challenges – but one of the most pressing is the shortage of skilled workers. Without qualified people, the other tasks cannot be tackled either. Automated and autonomous systems can cushion the problem, but not solve it, because: »Every automation system needs skilled personnel to help make key decisions,« says Holger Klempnow, CEO of KleRo GmbH Roboterautomation. »Without this personnel, a production hall cannot be expected to run reasonably in the near future.« One key aspect: The human ability to react flexibly to disruptions and unexpected or new situations is far from being technically replicable, even with AI. Especially in crisis and exceptional situations, employees are therefore a crucial resilience factor.

Against the backdrop of demographic change and a shift in values among younger generations, the problem is not expected to ease in the near future. Creative solutions are therefore needed to recruit, retain and upskill staff, but also to support the existing workforce. It is necessary to increase the attractiveness of jobs in production, by making tasks diverse and allowing workers to make decisions, but also by reducing physical stress. Highly complex, integrated technologies must be made manageable for operators, even if their initial qualifications for handling them are not perfect. And the know-how of process experts must be secured within the company and made accessible to other employees.

Human-centered, context-sensitive assistance

Data-driven solutions offer a variety of approaches. If manufacturing processes become so complex that average machine operators can no longer identify ideal parameters to set them up with experience alone, interactive assistance systems can help. Based on sensor data or knowledge from specialists, they suggest suitable settings or guide people through the process in a context-sensitive manner. »In doing so, any support should nonetheless use and challenge the intelligence of employees,« says Prof. Schramm, BMW Group.

If this is not taken into account, SCHOTT also fears humans could feel powerless in the face of the process. »We need employees in the process, because they can react flexibly where a situation exceeds a system's decision-making capabilities,« summarizes Dr. Trinks. »At the same time, we want to use appropriate systems to support them in performing their tasks to the best of their ability and actively advance processes. We see the cooperative collaboration of employees with assistance systems as an approach in which both sides develop further in a learning process. The creative part and also the responsibility for decisions are currently still clearly on the human side.«

Direct versus indirect assistance

The large field of assistance systems can be roughly divided into two groups. Indirect assistance operates in the background, while direct assistance involves immediate human-machine interaction. Indirect assistance is essentially selection guidance based on data analysis. To prepare difficult decisions, data from sensors in machines, for example, are intelligently evaluated. The result is a context-sensitive selection of possible options. Direct assistance presents

»Setting up processes in the best possible way has become demanding. We integrate the necessary know-how into machine control systems to make it easier for people at the machine to do their job.«

Martin Kapp, KAPP NILES

information with models and dashboards in such a way that people can work with it – for example, to optimally set up a process or maintain a system with which they are not familiar down to the last screw. The challenge here is to design assistance in such a way that it can be operated intuitively and neither underestimates nor overwhelmes the person using it.

At Fraunhofer IPK, we address both types of assistance. Our field of activity ranges from solutions for semantic data networking and interpretation to user assistance systems appropriate to individual situations for a wide variety of applications. Identifying new and used components for assembly preparation or for reusing old parts belongs as much to our portfolio as supporting service personnel in maintenance operations.

Note the »EIBA« project
↪ on page 20

Maintaining health with ergonomics support

As it is becoming increasingly difficult to recruit junior staff for production, industry is undertaking great efforts to design work environments in such a way that experienced personnel can operate in them for a long time. Ergonomically optimized working conditions make a significant contribution to keeping employees in the company well into old age.

In this context, we develop wearable sensor and robot systems for ergonomic and force support that prevent injuries to the musculoskeletal system. Our ErgoJack® orthosis uses motion detection sensors to inform wearers when they are moving in an ergonomically critical way. In activities where an ergonomic posture is not possible – for example when working on objects at overhead level – exosuits for strength support such as PowerGrasp come to aid.

ErgoJack
↪ www.ipk.fraunhofer.de/ergojack-en

Knowledge management and qualification

The knowledge of process experts is as essential a resource for companies as energy or raw material for products. Making this knowledge available throughout a company requires effective knowledge management solutions. Our Competence Center Knowledge Management is a well-versed and experienced point of contact for this.

Contact CCKM
↪ www.ipk.fraunhofer.de/knowledge-competence-management

In addition, digitalization and networking in particular, as well as tailoring them to a company's specific requirements, create an increased need to further develop employees' skills. Intuitive training methods play an important role here. Technology-oriented training courses as well as serious games and realistic learning factories, in which production management and control methods are taught interactively, enable employees at all hierarchical levels to experience learning content first-hand and develop skills in a targeted manner. Some of our proven formats are already offered virtually and location-independent, others are currently being virtualized.

Information on our event program
↪ from page 66

Q&A

Operator-independent and Constant Quality through Intelligent Assistance


© SCHOTT AG

Dr.-Ing. Volker Trinks

Why are assistance systems an important topic for SCHOTT?
We are the world market leader for special glass tubes for pharmaceutical primary packaging materials such as glass containers for vaccines. In this area, quality requirements have been increasing for years. However, ensuring consistent quality requires a great deal of effort in the case of tubular glass, because every draw, meaning every manufacturing unit, is individual. In order to optimally adjust processes, which are also very individual, and to continuously monitor the result, we use optical technologies and intelligent methods of image processing and pattern recognition. Without such methods, the individuality of draws can hardly be captured.

Why is intelligent assistance indispensable in these areas?
There are several reasons. Setting up production processes in the best possible way has become extremely complex. Many parameters play into melting and shaping. Only highly qualified specialists are still able to model optimal interaction. Operators on the lines, on the other hand, need assistance systems that determine the best parameters possible at the specific moment to run a process. Such systems must also signal whether there is still potential for optimization. As far as quality assurance is concerned: During production, defects in the glass must be continuously detected and clearly classified in order to guarantee product properties with 100 percent accuracy. This is not possible with the naked eye, but it is possible with optical technologies combined with AI. With at least semi-autonomous control and optical inspection, we therefore achieve a very high level of quality across all sites. In addition, we secure the know-how of process experts to a certain extent.

Won't this make people on the line dispensable?
Definitely not in the near future. Digitization will not replace a single employee in production at our company, because only people can react flexibly to unusual situations. An important task is therefore to design increasingly complex systems in such a way that machine operators can use them well and receive all the information they need. For example, it must become transparent why a system makes a certain decision.

Dr.-Ing. Volker Trinks
SCHOTT AG

has been working at SCHOTT AG since 1991. He has been in charge of technology development at SCHOTT's Tubing business unit since 2016, which includes process and procedure development as well as the development of measuring systems, production machinery and the Optical Technologies specialist area. A relatively new focus is comprehensive process digitization and the use of AI methods.

SCHOTT produces around 30 million pharmaceutical containers per day worldwide. The preferred material is borosilicate glass, because it does not release any material to vaccines or medications. The majority of COVID-19 vaccines are filled in vials made of this glass. By the end of 2021, SCHOTT has supplied vials for more than five billion COVID-19 vaccine doses.

R&D Highlights on Knowledge and Assistance in Production

Providing people with the best possible support at work in production environments is one of our central concerns. To this end, we research and develop assistance systems as well as qualification methods for changing requirements in industry.

01 INTELLIGENT ASSISTANCE SYSTEMS FOR SERIES ASSEMBLY

Cockpit 4.0: CustOmized collaborative knowledge pilot for industrial technology

Better product quality, on-time delivery and flexible, trouble-free production – companies create the prerequisites for all these requirements with information-driven engineering. To this end, our researchers have developed an intelligent assistance system that links heterogeneous information semantically, interprets it automatically using machine learning methods, and 3D visualizes it in a context-sensitive manner. Operators thus always receive up-to-date product data in order to quickly solve manufacturing and assembly problems and avoid delays in the manufacturing process.

Partners:
- Rolls-Royce Deutschland Ltd & Co KG
- Brandenburg University of Technology Cottbus-Senftenberg

Funding notice:
This project is funded by the European Regional Development Fund (ERDF) and the State of Brandenburg.

EUROPEAN UNION
European Regional Development Fund

02 360° MACHINE MONITORING

Smart maintenance: from isolated solutions to a holistic concept

The total failure of a machine tool is a nightmare scenario in production. But even small deviations a machine's path control, caused for example by unwanted vibrations, can turn a workpiece into scrap. We develop smart maintenance systems for machines and systems that enable intelligent condition monitoring, failure forecasts and digital maintenance assistance. Irregularities as well as damages are detected and classified at an early stage using machine learning and the need for action is visualized with a traffic light system. Even the smallest irregularities are detected before they cause damage. Technical specialists are automatically notified and receive intuitive instructions on how to process service calls. This reliably prevents longer machine downtimes.

03

EXOSUIT FOR PRODUCTION AND LOGISTICS

PowerGrasp
Physically straining, manual tasks are part of everyday life in many companies, despite automation and digitalization. Our »PowerGrasp« exosuit gives workers in production and assembly ergonomic and strength support without restricting their movements. Both the single- and dual-arm models offer a textile vest's wearing comfort and are, at a total weight of 6.5 kilograms, significantly lighter than other active exoskeletons. The reason is the reduced back module, which houses a mobile compressed air supply and control system, a rechargeable battery and an embedded control unit. PowerGrasp has so far been implemented for arm and wrist joints and is designed for 50 to 150 overhead work cycles. Here, the system provides not only classic force balancing, but also situational and AI-assisted regulation of relief – allowing it to respond to user fatigue with increased assistance.

Selected partners:
- Würth Elektronik GmbH & Co. KG
- Schunk GmbH & Co. KG
- Volkswagen AG
- Universität der Künste Berlin (UdK)
- Evangelische Hochschule Nürnberg

Funding notice:
This research project is funded by the German Federal Ministry of Education and Research (BMBF).

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04

WITH ARTIFICIAL INTELLIGENCE TO A NEW JOB PROFILE

KIRA Pro: AI-based role navigator and automated learning path determination for continuing vocational training in the manufacturing sector
A successful digitalization strategy also includes qualifying employees for new tasks. But how do you decide which employees are best suited for certain new roles? What training do they need to acquire the necessary knowledge for the changed tasks? Together with training providers and SMEs, we are developing an AI-based role navigator to help industrial companies make the necessary decisions. With its help, companies can derive individual and industry-specific learning paths for their employees and identify suitable training opportunities. The goal is to integrate 3,000 occupations and 12,000 skills from the European ESCO framework into the software in the future.

Partners:
- Peers Solutions GmbH
- FBT Feinblechtechnik GmbH
- Harms und Wende GmbH & Co. KG

Funding notice:
This research and development project is funded by the Federal Ministry of Education and Research (BMBF) in the INVITE (Digital Platform for Continuing Vocational Education and Training) innovation competition and supervised by the Federal Institute for Vocational Education and Training (BIBB).

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Federal Ministry of Education and Research

bibb Federal Institute for Vocational Education and Training

Sustainability and Environmental Compatibility

Greenwashing Is Yesterday's News

For a growing number of companies, sustainability is no longer just a marketing argument, but an economic necessity. In a time characterized by supply bottlenecks for raw materials and rapidly rising energy prices, using scarce and expensive resources efficiently is gaining importance. Zero emissions and CO_2 neutrality are also increasingly coming into focus.

Our solutions for this topic area

- **Energy and resource efficiency** through optimal process parameters
- **Lifecycle design** based on sustainability criteria
- **Remanufacturing and refurbishing** for material efficiency and waste prevention
- **Circular economy concepts** for sustainable production of goods
- **Sustainability benchmarking and cockpits** for future-oriented business design

There are many approaches to shaping a sustainable economy. Perhaps the most sustainable one – to stay in the terminology – is that of »strong sustainability«: This concept places ecology at the center of all efforts. The idea is that a strong social system can only be formed within an intact ecosystem, and only a strong social system will produce an economy that functions in the long term. A society that exploits its environment beyond its regeneration capacity is not economically viable in the long term, let alone capable of survival.

More sustainability is therefore achieved first and foremost through ecological action. The importance of ecological action is currently being recognized more strongly than ever before. Just a few years ago, energy efficiency and the sparing use of resources were in large parts of the economy primarily sales arguments for companies that wanted to »give themselves a green makeover«. Now they are becoming a prerequisite for competitiveness. Since energy prices have exploded and even raw materials from which one would not have expected this – wood, for example – have become a luxury good, it has become clear, at the very latest: Things cannot go on as before.

Saving energy, reducing emissions

The areas where the pressure to act is currently greatest are energy efficiency, closely linked to CO_2 neutrality. Energy is becoming increasingly expensive. The causes lie, on the one hand, in market effects. Emerging economies are increasing demand, while international crises are tightening supply. On the other hand, CO_2 compensation payments, such as those enshrined in the German Climate Change Act, place an additional burden on industry. But they also create strong incentives. According to the Energy Turnaround Barometer 2021 published by the Association of German Chambers of Commerce and Industry (DIHK), a third of German companies want to become climate-neutral by 2030 or sooner. To remain competitive, especially internationally, their energy consumption must drop noticeably.

»The goal is to run production with as little energy as possible.«

Anne-Katrin Tomys-Brummerloh, Daimler Truck

Here, too, data-based approaches are interesting. Intelligent control technology, such as we have developed together with the company ÖKOTEC Energiemanagement, can infer ideal setpoints from energy measurement data, which are then automatically transmitted to the relevant machines. In this way, the most energy-efficient operating mode is not only determined, but directly set on the machine. Advances in artificial intelligence will in the coming years leverage additional potential in this area. Further approaches are offered by applying more energy-efficient basic physical principles in mechanical engineering.

Information on the EnEffReg technology
↪ www.ipk.fraunhofer.de/eneffreg-en

From linear to circular economy

The next challenge is obtaining raw materials. »Supply difficulties as well as significant price increases for primary products and resources are currently not only causing problems for internationally oriented German industry – they are affecting companies in all sectors and of all sizes,« the DIHK stated in a flash poll in August 2021. Against this background, we are strengthening our plea for a circular economy.

Our ideas on circular economy can be found in our customer magazine
↪ www.ipk.fraunhofer.de/futur-2020-1-en

The widespread linear economy entails a disproportionate consumption of resources. The problem was already evident before the COVID 19 crisis made the scarcity of raw materials an issue for society as a whole. Modern economy extracts raw materials from its environment to produce goods that are used and then disposed of. With the amount of goods that a growing world population needs and demands, this economic method reaches its limits.

Circular economy postulates a regenerative system. Energy and material cycles are slowed down or closed. This reduces resource and energy consumption, while producing less waste and emissions. An important key here is remanufacturing and refurbishing. At the end of their useful life, products are not disposed of but refurbished or broken down into components that can be recycled or even reused.

We help with remanufacturing
↪ more on page 20

Resource-saving lifecycle design

Where the use of raw materials cannot be avoided, they must be used in a material-saving manner. The best way to do this is to make the entire lifecycle of a product sustainable right from the start. Even the first decisions that product developers make have a direct impact on the ecological balance of products. For example, it is not enough for them to be power- or fuel-efficient in operation. »Real« sustainability must also take into account how much energy and material is used in manufacturing and under what conditions the product is produced – for example, which social standards were decisive in the process. And: to what extent it can be disposed of with little waste at the end of its service life.

We drive sustainable concepts for maintenance and repair in cooperation with Werner-von-Siemens Centre for Industry and Science (WvSC)
↪ www.ipk.fraunhofer.de/WvSC-en

Our researchers are therefore looking at a wide range of solutions to make products sustainable over their entire lifecycle. This begins with product creation and ends with the use of biopolymers that can be disposed of without leaving residues.

Demonstrating and communicating corporate responsibility

Admittedly: Sustainability means effort, and that comes at a price, too. Energy efficiency, for example, is not possible without investing in modern production technology. But the good news is that it pays off. Consumers are increasingly rewarding sustainability in their purchasing decisions. Companies are therefore well advised to make their efforts transparent, for example in their financial reporting. With the Integrated Sustainability Cockpit (INC) and other methods, we provide industry with suitable tools for this purpose.

In conjunction with appropriate data management, such solutions make a decisive contribution to prove responsible action. Corporate social responsibility is motivating a growing number of companies to provide evidence of the origin and manufacturing conditions not only of their products, but also of their products' components. In some cases, such evidence is even mandatory. At this point, a look at the supplier network becomes interesting again. Being able to show not only in one's own company, but also in the manufacturing processes of supplied components under which conditions they were manufactured, doesn't just increase credibility, but also facilitates certifications.

»The diversity of evidence required along the product lifecycle is increasing dramatically worldwide, including in the area of corporate social responsibility.«

Andreas Kühl, KSB

Information on INC
↪ www.ipk.fraunhofer.de/inc-en

Q&A

Sustainability Potentials Identified

Prof. Dr.-Ing. Holger Kohl

Prof. Dr.-Ing. Holger Kohl
Fraunhofer IPK

is deputy director at Fraunhofer IPK and head of the Sustainable Corporate Development chair at Technische Universität Berlin. His research focuses on the development of sustainable value creation systems as well as process and performance management systems for sustainable corporate development.

How can production science help to fight global warming?
It is important that we think and research along the entire process chain. Which are the points in a product lifecycle where most CO_2 can be saved? One method to answer this question is lifecycle assessment, which shows exactly where the greatest impact can be generated. This enables us to identify the major CO_2 drivers in a targeted manner and derive cost-effective and efficient measures.

What are the best levers here?
The first major issue is resource efficiency. With the current state of production technology, the production of steel, aluminum, plastics and cement alone will cause around 800 gigatons of CO_2 in the 21st century – which is enough to miss the two-degree target. That's why it is important to recycle such materials in the sense of a circular economy, also to reduce the global waste mountain. The second important issue is energy consumption.

What should manufacturing companies consider in their electricity consumption?
Germany is one of the countries with the highest energy prices. CO_2 pricing and global conflicts will only exacerbate this situation. Industry is therefore well advised to save energy wherever possible. Our R&D work aims at exploiting potentials for our partners down to the last bit, for example in the field of automatic energy efficiency control of supply technology or in optimizing production processes.

Tons of waste in Germany per year . . . . . 417 million
German electricity price in global comparison . . 15th place (of 133)
Minimum price per metric ton of CO_2 from 2025. . . . . €55
German manufacturing sector's share of energy consumption across all production sectors. 42%
Employees in the German recycling sector 35,000

R&D Highlights on Sustainability and Environmental Compatibility

Manufacturing with nature and the environment in mind: We show how we help companies become more sustainable from overall management to individual processes.

01

LIFECYCLE ASSESSMENT OF WELDING PROCESSES

Welding processes require large amounts of energy and resources, which is critical from an ecological point of view. This makes it all the more important to put greatest emphasis on sustainability and efficiency in welding. To this end, we rely on lifecycle assessment. The ISO-standardized procedure is an excellent method for estimating the potential environmental impact of processes or products over their entire lifecycle. Environmental and social impact is assessed at various lifecycle stages. We use our expertise in joining and coating technology and additive manufacturing to create individual sustainability assessments. To this end, we develop environmental accounting methods with lifecycle assessments (LCA), social lifecycle assessments (SLCA) and critical reviews in accordance with ISO 14040/44 and DIN/TS 35235 for production processes.

02

INDUSTRIAL ENERGY MANAGEMENT IN THE INTERNET OF THINGS (IOT)

IoT-based solutions for monitoring and optimizing energy efficiency in production

Manufacturing accounts for more than 40 percent of the energy used by the German economy. Rising energy prices, ecological aspects, security of supply and the integration of renewable energies into the power grid are stressing the importance of systematic energy management. Together with CONTACT Software GmbH, we are developing approaches to integrate industrial energy management into the existing IoT platform CONTACT Elements for IoT. Combining systematic energy recording and digital twins makes it possible to dovetail efficiency measures with holistic digitalization.

Partner:
CONTACT Software GmbH

03

INTEGRATION OF BIOLOGICAL PRINCIPLES INTO INDUSTRY 4.0

BioFusion 4.0: further development of Industry 4.0 by integrating biological principles

»BioFusion 4.0« transfers principles from nature into industrial manufacturing. The goal is sustainable and circular value creation. Solutions for intelligent recycling of valuable materials are being advanced, as is engineering of biologically transformed products and processes. In addition, the potential of biointelligent assistance systems for workers and bio-based materials for production are being investigated. One example: biogenic polymers are created from waste fats, and then used to produce spare parts or small orthoses on demand using 3D printing, while also assessing their carbon footprint. After use, they can be fully biodegraded.

Selected partners:

- Mercedes-Benz AG, Berlin plant
- Bral Reststoff-Bearbeitungs GmbH
- COLLIN Lab & Pilot Solutions GmbH
- Arburg GmbH
- GreenDelta GmbH

Funding notice:

This research and development project is funded by the German Federal Ministry of Education and Research (BMBF) within the Framework Concept »Research for Tomorrow's Production« and managed by the Project Management Agency Forschungszentrum Karlsruhe, Production and Manufacturing Technologies Division (PTKA-PFT).

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Federal Ministry of Education and Research

PTKA Projektträger Karlsruhe
Karlsruher Institut für Technologie

04

BENCHMARKING AS AN INSTRUMENT OF SUSTAINABILITY MANAGEMENT

Sustainability benchmarking for medium-sized companies

Sustainability is becoming increasingly relevant even for small and medium-sized enterprises. Companies that want to act in an all-around sustainable manner must balance the three sustainability dimensions of economy, ecology and social issues. This in itself is a challenge, as is integrating the dimensions into management. The project »Sustainability Benchmarking for SMEs« has developed a tool that supports companies precisely in this area: by comparing key figures to determine their position. Users get an overview of their strengths and weaknesses, can compare themselves within their industry and tap unused potential. This tool is now available as a transfer module, which we use to pave the way to greater sustainability for our partners.

Partner:

Bundesverband mittelständische Wirtschaft e.V.

Funding notice:

The Deutsche Bundesstiftung Umwelt (German Federal Foundation for the Environment) is funding the project as part of the funding theme »Tools and competencies for sustainability assessment and strengthening sustainability awareness and action«.

sponsored by
DBU
Deutsche Bundesstiftung Umwelt
www.dbu.de

Fraunhofer IPK: About Us

Fraunhofer IPK in Berlin offers system solutions with a strong digital focus for the entire spectrum of industrial tasks – from production management, product development and manufacturing to maintenance of capital goods.

Our Mission

Our goal is a sustainable production – inventive, human-centered and resource-efficient.

With the help of application-oriented research, we develop solutions along the entire industrial value circle. Our guiding idea is a digitally integrated production in which man and machine interact on the basis of data and can thus adapt flexibly and proactively to changing requirements.

Fraunhofer IPK is a research and development institution in the field of production technology. With our distinctive IT competency, we offer system solutions, individual technologies and services for digitally integrated production. We provide comprehensive support to companies from product development, planning and control of machines and systems, including technologies for parts manufacturing, to comprehensive automation and management of factory operations. We also transfer production engineering solutions to areas of application outside industry, such as traffic and safety.

As an institute of the Fraunhofer-Gesellschaft, we tailor our work to fit the needs and requirements of our customers and partners. With its market orientation and high real-world value, our R&D helps to sharpen their long-term competitive edge. We develop forward-looking novel solutions and modernize, optimize and upgrade existing technologies and applications.

Fraunhofer IPK Profile

Established:
1976

Staff:
358 employees

Budget in 2021:
20.5 Mio €

Spin-offs:
60

Location:
Production Technology Center (PTZ) Berlin

Customers:
Industry, SMEs, associations, administration, politics

International markets:
Europe, Asia, North and South America

Board of Trustees

The Board of Trustees is Fraunhofer IPK's direct line to renowned companies, associations and public institutions. The members of the board advise the institute and promote exchange with industry and funding agencies. Chairman is Dr. Ansgar Kriwet.

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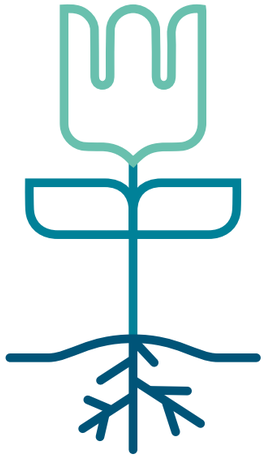
The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. A trailblazer and trendsetter in innovative developments and research excellence, it is helping shape our society and our future. Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany.

The Fraunhofer Institutes are the central link between research and practice: We transfer basic innovations from fundamental research into industrial application.



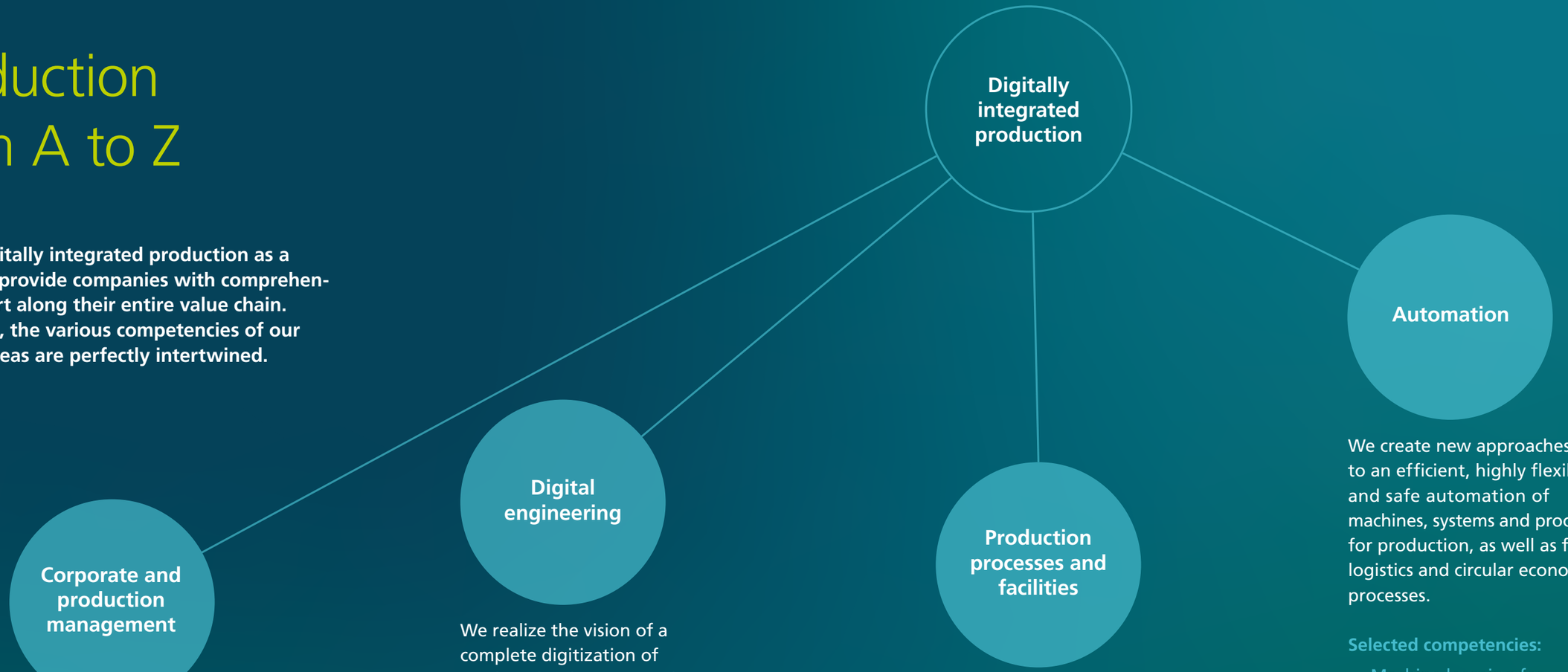
Industrial application
– Companies

Application-oriented research
– Fraunhofer Institutes
– Industry-owned development centers

Basic research
– Universities
– Max Planck Institutes
– Helmholtz Centers

Production from A to Z

We see digitally integrated production as a mission to provide companies with comprehensive support along their entire value chain. To this end, the various competencies of our research areas are perfectly intertwined.



Corporate and production management

We develop solutions for managing the sustainable and digital transformation of manufacturing companies. In addition, we help to introduce resilient and agile processes as well as to plan and realize sustainable and circular value creation systems.

Selected competencies:

- Modular and adaptive process chains
- Sustainable value creation and circular economy
- Knowledge and competence management

Digital engineering

We realize the vision of a complete digitization of product development and planning processes – so that you as a manufacturer or user can consider the later phases of your product's lifecycle at an early stage.

Selected competencies:

- Digital twins
- Data management and PLM
- Model-based systems engineering

Production processes and facilities

We optimize existing production systems, develop new machines, machining strategies as well as manufacturing technologies, including for joining and coating, and realize future-oriented tool concepts. We also offer special expertise in the field of machine and system management.

Selected competencies:

- High-performance, precision and micro manufacturing
- High-performance machines and system management
- Additive manufacturing

Automation

We create new approaches to an efficient, highly flexible and safe automation of machines, systems and processes for production, as well as for logistics and circular economy processes.

Selected competencies:

- Machine learning for industrial processes
- Industrial image processing
- Industrial robotics

More information:
www.ipk.fraunhofer.de/expertise

Research for Your Application

Our commercial customers include small and medium-sized enterprises in particular, as well as globally operating industrial and service companies from a wide range of sectors. Our researchers' expertise focuses on five industries:

Mechanical and plant engineering
As one of the largest and most research-intensive industrial sectors in Germany, mechanical and plant engineering is currently facing challenges in the areas of Industry 4.0, environmental protection, energy and resource efficiency as well as electromobility.

Tool and mold making
Whether series and mass production or direct manufacturing of microcomponents and microstructured components: Our services range from the development of special technological solutions to the development of production equipment and the creation of entire process chains.

Automotive
An industry facing major upheaval: Key framework conditions are being transformed. Changing drive concepts, new materials and stringent political requirements are posing challenges for manufacturers and suppliers.

Aerospace technology
Climate protection is the key driver of technological innovations in aviation. Introducing hybrid technologies and electric drives as well as certifying new materials will revolutionize aircraft design in the coming decades.

Medical technology
Medical technology is undergoing profound changes. Competition, cost pressure, and challenges posed by digitalization and stricter regulatory requirements are putting pressure on the industry.

In addition to topics from specific areas of expertise, we also drive forward interdisciplinary topics that are of particular concern to industry. These are currently for example:

Industry 4.0
Production is becoming networked and thus intelligent and flexible. People, workpieces and machines are linked to each other using state-of-the-art information and communication technology. As a result, all production-related information is continuously available in real time – workers, objects and systems can communicate and cooperate directly with each other.

Additive manufacturing
The potential of this manufacturing method lies in drastically shortened development times and cost-efficiently produced highly complex component geometries. While aviation and medical technology were the main drivers recently, the technology is now also being used in toolmaking, special-purpose machinery and automotive engineering.

Smart maintenance: from isolated solutions to holistic concepts
Machines and systems are capital goods that must function reliably to ensure that their purchase is worthwhile in the long term. Smart maintenance records machine conditions in real-time, detects damage and supports maintenance with intelligent assistance.

Artificial intelligence
Human workers at the center of production are the focus point of our activities in the field of artificial intelligence. We use technologies such as neural networks as well as machine vision and learning to make production processes safer and more efficient and to provide employees in all areas of industry with the best possible support.

Digital twins
With increasing automation in production, the demand for accuracy is growing. Mistakes already made during planning and design often result in considerable additional work and higher costs. With digital twins, processes are developed and carefully tested on pilot systems. Errors are avoided and resources are saved.

What Our Partners Say about Us

Whether you are a global corporation or a local medium-sized company: Fraunhofer IPK is your research and development partner on the road to digital transformation. We impart knowledge in the field of production technology and develop methods to improve the management of organizations, services and production as well as environmental and quality management.

»

In the »Scan2DMU« project, Fraunhofer IPK has developed a solution that allows us to automatically compare our CAD geometries with scan data. We can match our digital models and see where we have discrepancies.«

Sebastian Riedemann
Lufthansa Technik Group

»

BMW Motorrad aims to be on the forefront, especially concerning product and production innovation. At the Berlin plant, we have a very broad technological base. Fraunhofer IPK has been supporting us as a long-term partner with a measure of expertise that is second to none.«

Helmut-Joseph Schramm
BMW Motorrad

»

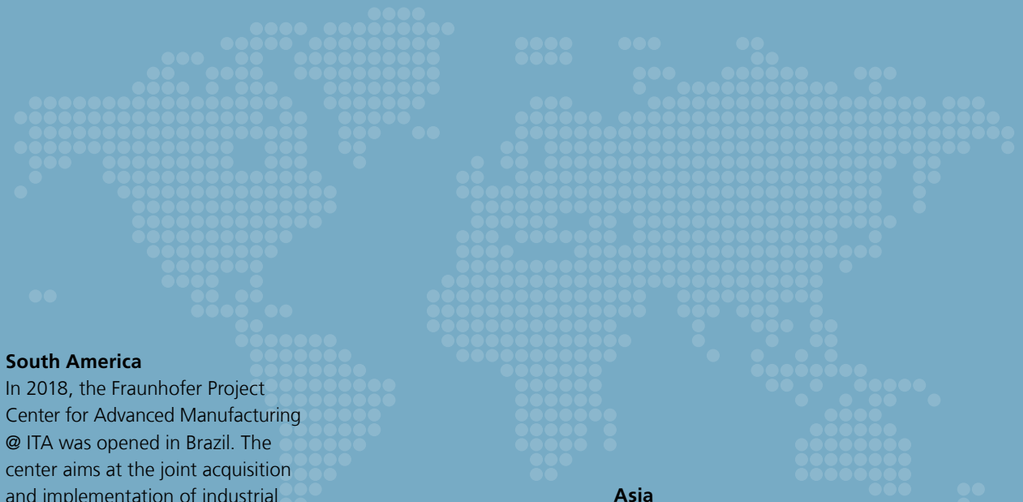
Machine learning and vision are making it less complex to sort old parts. They are the perfect complement for humans at the center of production. In partnership with Fraunhofer IPK, we are developing an AI technology to automatically detect end-of-life parts to make our processes less likely to fail and globally scalable.«

Markus Wagner
Circular Economy Solutions GmbH

International Cooperation

We work with partners in numerous regions worldwide. There are clear prerequisites for our international commitment: scientific value for Fraunhofer IPK on the one hand and positive effects for both Germany and the respective partner country on the other.

Europe
EPIC is a European knowledge center for cyber-physical production systems. Its mission is to accelerate innovation, implement industrial solutions, train new generations of highly qualified professionals and support the development of a sustainable and competitive European manufacturing ecosystem.



South America
In 2018, the Fraunhofer Project Center for Advanced Manufacturing @ ITA was opened in Brazil. The center aims at the joint acquisition and implementation of industrial and publicly funded research and development projects.

Since 2012, Fraunhofer IPK has been supporting the Brazilian industry training service SENAI in setting up innovation institutes based on the Fraunhofer model.

Asia
ENRICH in China was established in October 2017 with the support of the European Commission to provide unique services to European research and technology institutions as well as companies seeking a competitive presence in the Chinese market.

More information:
www.ipk.fraunhofer.de/international-en

Our Facilities

True excellence in research calls for the brightest minds and an excellent infrastructure. In order to develop solutions and products for our clients, Fraunhofer IPK is equipped with state-of-the-art development environments.

Central test area
The circular hall is where most of our experiments take place. Our high-tech test stands include numerous machine tools, assembly systems, robots, VR environments, and stand-alone devices.

Application Center for Microproduction Technology – AMP
The three AMP laboratories are equipped with state-of-the-art machines and measuring technology for high- and ultra-precision machining and process development. High-precision air conditioning technology ensures constant ambient conditions – for the most accurate results.

Industrie 4.0 Transferzentrum
In the institute's own transfer center, we show selected application-ready solutions from our applied research for industry in interactive exhibits.

1986
Main building inauguration

2011
AMP inauguration

10,000 sqm
Total floor space

2,350 sqm
Floor space AMP

3,200 sqm
Test area

100
Test stands

18 meters
Ceiling height in the central test area

More information:
www.ipk.fraunhofer.de/site

Technology and Knowledge Transfer

Besides research and development, rapid technology transfer is the most important task for our institute. For this purpose, we offer various event formats to supplement our direct exchange with our partners in the project context. Be part of it!

With our event and professional education program MEHR KÖNNEN, we transfer technology-based know-how directly into business practice. In our certification programs, conferences, industry working groups, seminars and workshops, specialists and managers gain scientifically sound and implementation-oriented qualification in the areas of design, development, production, quality, and management. We also enable companies and organizations to use the potential of digital transformation technologies such as Artificial Intelligence, Smart Data, Internet of Things, 5G and Cloud Computing for their production and the associated business models.

In addition, with our Innovation Days we offer companies an individual format in which we present highly specialized technologies and solutions – tailored to the specific questions and needs of the respective customer. Together with you, we discuss which technologies will bring new benefits to your product portfolio, which solutions will increase the efficiency of your performance processes, and how you can overcome transformation challenges with your teams. In bilateral R&D projects, we then support and accompany you in implementing and integrating innovations in your company.

More information:
www.ipk.fraunhofer.de/events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Rethinking Production

Production as a driver for an industrial society in transition

At our Production Technology Colloquium (PTK) on September 14–15, 2023, you will learn which innovative technologies, methods and business models can be used to achieve sustainable and digitally integrated production to ensure future competitiveness. Experts and executives from business and science will present successful approaches and strategies for CO_2-neutral production as well as current Industry 4.0 solutions.

More information: www.ptk.berlin

MEHR KÖNNEN

Certification Program

Mastering Digital Twins, self-paced online certification program

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»Mastering Digital Twins« is designed as an English-language online learning program. It will give you in-depth knowledge about all lifecycle phases of digital twins (ideation, design, development, operation, and end of life), and a clear understanding of their business potential in different industry scenarios.

More information:
www.ipk.fraunhofer.de/mastering-digital-twins-en

Serious Game

LearnFactory 5.0, educational game on demand

© Fraunhofer IPK / Larissa Klassen

We have extensive experience in developing serious games for production management and control tasks. For many years, our interactive seminar for implementing a customer-oriented, human-centered, flexible and sustainable production has proven itself. So far, the seminar takes place in presence, an online version is in development.

More information:
www.ipk.fraunhofer.de/learnfactory-en

Training Course

Mastering PLM, online training course

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Our Mastering PLM program teaches practice-oriented knowledge and skills in Product Lifecycle Management (PLM). Participants will learn the basics for the management of complex systems and pass through the value creation chain of a product over the entire lifecycle.

More information:
www.ipk.fraunhofer.de/mastering-plm

Our Experts for Your Topic

Finding answers to the challenges facing industry – Fraunhofer IPK has the right people to do just that. Contact our thought leaders directly and in person.

Production processes and facilities

Prof. Dr. h. c. Dr.-Ing. Eckart Uhlmann
Institute Director
Phone +49 30 39006-100
eckart.uhlmann@ipk.fraunhofer.de

Topics:
Industry 4.0, digitalization in production, additive manufacturing, 3D printing, smart maintenance, condition monitoring, mechanical engineering, production systems, machine tools and system management, manufacturing processes, microproduction technology

Digital engineering

Dr.-Ing. Kai Lindow
Phone +49 30 39006-214
kai.lindow@ipk.fraunhofer.de

Topics:
Product lifecycle management, product-related sustainability, model-based systems engineering, digital product twins, intelligent data and model networking, model optimization and validation, virtual and augmented reality

Corporate and production management

Prof. Dr.-Ing. Holger Kohl
Deputy Director
Phone +49 30 39006-233
holger.kohl@ipk.fraunhofer.de

Topics:
Sustainable and digital transformation, planning of digitally integrated production systems, agile process management, resilient production, sustainable value creation systems and circular economy, benchmarking, knowledge and competence management, innovative learning formats and factories

Joining and coating

Prof. Dr.-Ing. Michael Rethmeier
Phone +49 30 39006-220
michael.rethmeier@ipk.fraunhofer.de

Topics:
Welding processes and technology, thick and thin sheet welding, coating processes, welding simulation, welding sequences, additive manufacturing: laser powder cladding, wire arc additive manufacturing

Automation

Prof. Dr.-Ing. Jörg Krüger
Phone +49 30 39006-178
joerg.krueger@ipk.fraunhofer.de

Topics:
Automation, industrial robotics, human-robot collaboration, AI in production, machine vision, optical quality control, energy efficiency optimization

Imprint

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