THE MAGAZINE OF THE **PRODUCTION TECHNOLOGY CENTER BERLIN**

futur

VISION | INNOVATION | REALIZATION

HUMANS AND MACHINES

From Cells to Lines

New technology for modularization in assembly helps manufacturers to make their processes future-proof. The goal is to integrate humans in the best possible way.

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**INSTITUTE
PRODUCTION SYSTEMS AND
DESIGN TECHNOLOGY**

**INSTITUTE MACHINE TOOLS
AND FACTORY MANAGEMENT
TECHNISCHE UNIVERSITÄT BERLIN**

**Could this friendly face
belong to your future co-worker?**

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Production Technology Center (PTZ) Berlin

PROFILE The Production Technology Center (PTZ) Berlin houses two research institutes: the Institute for Machine Tools and Factory Management IWF of the TU Berlin and the Fraunhofer Institute for Production Systems and Design Technology IPK. As production-related research and development partners with a distinctive IT competence, both institutes are in international demand. Their close cooperation in the PTZ puts them in the unique position of being able to completely cover the scientific innovation chain from fundamental research to application-oriented expertise and readiness for use.

We provide comprehensive support to companies along the entire process of value creation: Together with industrial customers and public-sector clients, we develop system solutions, individual technologies and services for the process chain of manufacturing 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.

DEAR READERS,

Humans and machines have come a long way together. The first steam engines at the beginning of the 18th century made the first industrial revolution possible, while their electrification, automation and digitalization were formative for the second and third waves of industrialization. Today, we are getting ever closer to the vision of a digitally integrated production as developed at the Production Technology Center (PTZ) Berlin.

In this next phase, the increasing networking of entire production systems will make the possible interactions between humans and machines, as well as between machines amongst themselves more complex than ever. Today, many factories produce highly individualized products that can be configured as desired, making it necessary to flexibly integrate machine tools, robots, mobile systems or manual workstations with operator guidance into ever new processes. In order to make the interfaces between these elements of production environments with their different operational logics as smooth as possible, creative solutions have to be found by academia and transferred to industrial application. Having introduced human-centered automation as a research focus back in the 1980s, we at PTZ Berlin are ideally positioned for this.

The ethical, legal and social implications that come into play when designing these solutions were the topic of a discussion from the series »Science and Culture in Conversation« by Fraunhofer IPK in cooperation with the Austrian Cultural Forum Berlin. We summarized the conversation for FUTUR.

In this issue, we also explain how mobile robots learn to »see« in order to safely navigate their environment – even when humans are present with their difficult-to-predict, often spontaneous motion sequences. Visuals are also at the center of our photo series, in which we show how a digital assistance system developed by Fraunhofer IPK and CONTACT Software ensures smooth processes in the maintenance, repair and overhaul of machinery and equipment. The question of how to optimally integrate humans into the automation of particularly complex assembly processes is the focus of an interdisciplinary team of researchers with automation and management expertise at Fraunhofer IPK. With the help of their newly developed modular technology, setup times in assembly can be reduced to a fraction of their previous duration.

In short, with this issue of FUTUR we would like to give you a deeper insight into the multi-faceted world of collaboration, cooperation and communication between people and machines.

We hope you enjoy reading this issue.

Yours

Eckart Uhlmann

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»The cui bono question is very relevant: What is automation used for and whom does it serve?«

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Digital MRO assistance is becoming smarter
↳ More on page 30

People still have to lend a hand – but it is becoming more convenient
↳ More on page 42

»Until recently, the term ›user errors‹ was commonly used. Since human-centered development processes have been established, however, it has become increasingly clear that ›operating errors‹ have their origin in inadequately designed user interfaces.«

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AI assistance in additive manufacturing with metals
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SHORT CUTS

IN DETAIL

© BMW Motorrad

Who is collaborating with whom here?

↳ Learn more on page 22.

NUMBER OF THE ISSUE

70 %

of people interviewed for a study by Fraunhofer IAO stated that physically strenuous activities should be left mostly to robots.

↳ **Find out which activities the respondents attribute exclusively to humans** on page 10.

DIGITALLY INTEGRATED PRODUCTION – FRAUNHOFER IPK PRESENTS TRENDS FOR RESEARCH AND DEVELOPMENT

Fraunhofer IPK asked industry representatives what challenges and needs manufacturing companies will be facing in the next few years. The result: Five technology topics will be top priorities across all sectors to ensure manufacturers can not only meet everyday customer expectations, but also manage crisis situations. Digitalization and networking are becoming indispensable keys to success.

↳ **Read our trend report for 2022/2023 free of charge at** www.ipk.fraunhofer.de/trendreport-dip-en

THE DAWN OF THE HYDROGEN AGE FOR FREIGHT MOBILITY

The German Federal Ministry of Digital Affairs and Transport is funding the »H2GO – National Fuel Cell Production Action Plan« project with around €80 million. H2GO brings together the activities of 19 Fraunhofer institutes, including Fraunhofer IPK, with the aim of significantly reducing CO_2 emissions in freight mobility.

↳ **Further infomation [German only] at** www.ipk.fraunhofer.de/h2go

WELL SAID

»As long as we have a gap between fundamental research and application, we will have a big problem harnessing the potential of AI in production. We would have to put at least as much effort and resources into empowering the people who are supposed to use AI as we do into fundamental research methods.«

Prof. Dr.-Ing. Jörg Krüger

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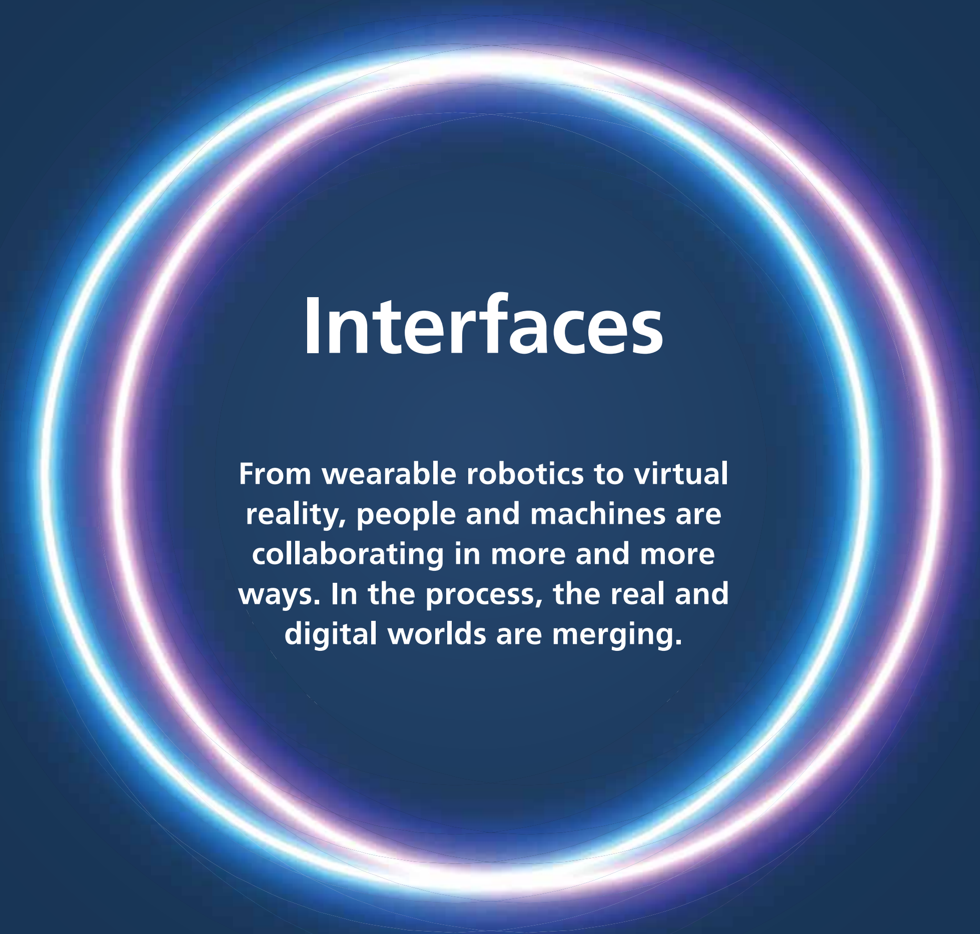
NEW GENERATION OF SUSTAINABLE BATTERIES IN EUROPE

The project »Battery Pass« is a new German-funded R&D project for a European target market, but with global outreach. It is designed to develop core data specifications, technical standards and dissemination for the fulfillment of the ›EU battery passport‹. The project, named Battery Pass, will provide the foundations of an interoperable, open standard, scalable data platform, and provide the basis for the rapid development of a battery passport and its market implementation. The Battery Pass will empower Europe to become a leader in the digitalization of the battery supply chain and electromobility, making a unique contribution to climate protection, social responsibility, energy and the circular economy. This will significantly transform the energy sector and increase its resource independence and competitiveness.

↳ **Further information about Battery Pass at** www.ipk.fraunhofer.de/batterypass-en



Interfaces

From wearable robotics to virtual reality, people and machines are collaborating in more and more ways. In the process, the real and digital worlds are merging.

1.
A robot may not injure a human being or, through inaction, allow a human being to come to harm.

2.
A robot must obey orders given it by human beings except where such orders would conflict with the First Law.

3.
A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

The three laws of robotics according to Isaac Asimov may come from a fictional story – but in times when humans and machines cooperate more closely than ever before, they seem more relevant than ever. Industrial companies must guarantee the safety of their employees and at the same time the best possible operation of their plants. For both, it is essential that communication across system boundaries – that is between people and machines – is as smooth as possible.

While Asimov still centered his science fiction narratives around the interaction with robots as physical entities, today many more aspects of this type of interaction have to be considered. For it no longer takes place only within the material space, but also in the virtual space, also called cyberspace, in which digital data form the basis of communication.

Of course, these two systems are not strictly demarcated from one another. The »real« and the »digital« worlds are not dual opposites, but are in many cases connected by interfaces: the dashboard of a machine tool, which a skilled worker uses to initiate a machining process. The sensor that transmits real-world stimuli as an electronic signal, which then becomes the data point of a digital twin and thus provides information about the status of a system. Or the VR goggles, which visualize digital models, making the virtual world perceptible to the human senses. These are all examples of border crossings in which people enter into direct exchange with machines. The space in which this exchange is made possible by the interaction of virtual, augmented and physical reality is now also known as the »metaverse.«

INFLEXIBLE AND RUTHLESS – THE OLD IMAGE OF THE INDUSTRIAL ROBOT

For a long time, industrial robots were known primarily as steel motion machines in the automotive industry. But advances in sensor technology and algorithms are now increasingly enabling new and more flexible applications. This is opening up new processes and even entire domains for robotics. Contrary to many prejudices, however, the focus is often not on replacing, but on collaborating with humans.

Conventional industrial robots are characterized by their tireless diligence and consistent quality of work. At the same time, they are essentially rigid systems that continuously work through a predefined list of instructions. Accordingly, a carefully structured environment is necessary for robots to develop their capabilities. In the process, humans not only introduce unrest into a carefully balanced system, they often have to stay out of it for their own safety. After all, robots are basically blind to begin with and have neither the ability to notice the presence of humans nor the cognitive capacity to maneuver safely around them.

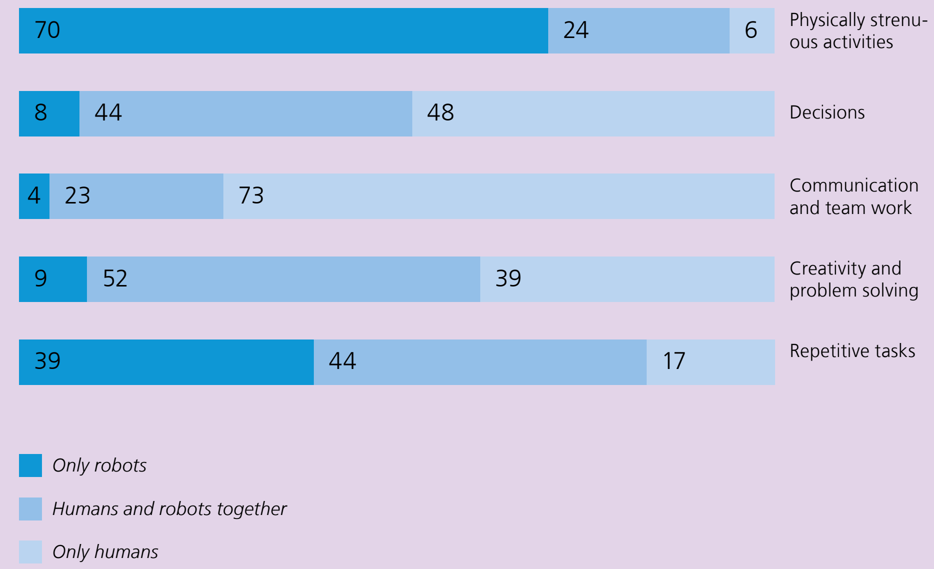
STRONGER TOGETHER

New sensor systems and intelligent approaches to data processing provide the basis for addressing these sensory and cognitive deficits of robots. New developments in force control and safety technology also permit them to leave their protective fences without posing a threat to humans. The interaction of intelligent robots and modern safety technology enables entirely new types of division of labor, which allows for parallel activities of humans and robots in closer spatial and temporal proximity. Previously manual activities can now be partially automated without valuable space being taken up by an additional safety cell. The greatest advantage of such approaches is that humans and robots can merge their different strengths. While robots continue to contribute significant power and endurance, humans can compensate for the weaknesses of conventional automation systems with their problem-solving skills and fine motor skills. Workplace ergonomics can also often be significantly improved by converting to human-robot collaboration.

Advances in sensor technology and algorithms are now increasingly enabling new and more flexible applications.

How are humans and robots supposed to handle different tasks in the future?

Diagram:
All figures in percent.
Source: *Own representation based on Fraunhofer IAO, »Homo Digitalis,« 2018.*



Images:
Human-robot collaboration in action: In addition to a suction pad and a force sensor, the robot is also equipped with a safety skin that enables direct collaboration in contact with humans. This allows humans to move 35 kg packages of solar panels effortlessly through space – with robotic colleagues.

Fraunhofer IAO came to a similar conclusion in its 2018 »Homo Digitalis« study. 70 percent of respondents said they would leave physically demanding tasks primarily to robots. Conversely, however, only a few trusted robots with the necessary decision-making and problem-solving skills to act independently. However, one in two could well imagine joint interaction between humans and robots.

ROBOTIC ASSISTANCE SYSTEMS

One way to leverage this potential is through direct physical interaction between humans and robots. At Fraunhofer IPK, new generations of robotic systems are being developed that can safely transport loads such as 35 kg packages of solar panels in a human-robot collaboration. Communication between the partners takes place through direct contact. Sensors determine the force exerted by a human on the package, and intelligent algorithms use this information to calculate the intended movement. Deep integration of the system into the robot's control system means that the processes take place within a control cycle, giving the human operator the feeling that the package is attached to a guiding rail along which it can be moved effortlessly. In the SHERLOCK project, researchers are also developing processes that use similar methods to allow simple interaction with robots in order to align components in an ergonomically favorable way.

Robotic support can also be much more discreet: Using a cordless screwdriver to screw components together overhead can fatigue the arm muscles in the long run. The active exosuit PowerGrasp uses compressed air to strengthen and support movements and thus relieve the strain on workers in assembly, as an example for a use case. The system is designed as a textile vest and does not restrict freedom of movement. Thanks to artificial intelligence methods, PowerGrasp recognizes both the type of movement and the degree of fatigue and can provide targeted support.

ARTIFICIAL INTELLIGENCE FOR MORE FLEXIBILITY

Human-robot collaboration also brings new challenges. For example, robots must learn to deal with changes in their environment that are initiated by humans and are thus unpredictable for them. They must therefore be able to detect deviations from a target state and subsequently react to them dynamically. Humans and robots must also be able to assess the current (movement) intentions of their counterparts.

To do this, the machines must become intelligent: Image processing algorithms, for example, make it possible to identify an inaccurately positioned screw and successfully carry on despite a deviation from the planned state. AI cannot only process images and videos, but also movements. For example, the PowerGrasp vest described above contains accelerometer and gyrometer sensors that measure and classify movements. To train the exosuit's artificial intelligence, the researchers first collect a dataset of typical hand movements and activities from the field of mechanical engineering in six-dimensional motion data. Neural networks with time components can not only recognize the activity in this, but also evaluate fatigue states.

BETTER TOGETHER

AI plays an important role in enabling technical systems to follow humans. In industrial production, numerous and sometimes very complex tasks can be automated. Not every scenario and every human movement can be anticipated and appropriate actions programmed. Instead, robots must learn to look, listen, feel and thus integrate themselves into the working world of humans. The more real-time information about their working environment is available in the process, the better. To get the most comprehensive picture possible of their environment, robots need »sensory organs« and a »brain«: suitable sensor technology and advanced data and information management.

Robots must learn to look, listen, feel and thus integrate themselves into the working world of humans.

Vice versa, humans also need support in communicating with machines. Digital assistance systems bridge the boundary between physical and digital worlds and lead to the metaverse advancing ever deeper into production-specific processes. This revolution in collaborative working, which focuses on people and their strengths – their almost unlimited creativity, but also certain fine motor skills – is helping to meet the challenges of today. For example, demographic change is causing an increasing shortage of skilled workers, which is particularly glaring in the technical sector. Aging workers and their invaluable expertise will soon be missing from companies. Virtual assistance systems have the potential to help both qualify new employees and reduce human effort overall.

From the smallest unit of individual human-machine interaction to large cyber-physical systems – at Fraunhofer IPK these topics are being advanced in many research and development projects. Our researchers are shedding light on important aspects that have often been neglected in everyday industrial life. For them, classic automation expertise goes hand in hand with software development, data management, factory planning and other relevant disciplines. This allows our scientists to transcend the »block thinking« between physical and virtual worlds that is still widespread in industry and thus develop the best possible solutions in the area of assistance systems, for example. In this way, research and development ensures that people have sustainable and useful helpers in robots and other machines in the long term. ◆

Image:
PowerGrasp uses compressed air to strengthen and support movements and thus relieve the strain on workers, for example in assembly.

The revolution in collaborative working focuses on people and their strengths.

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Of Robots and Men

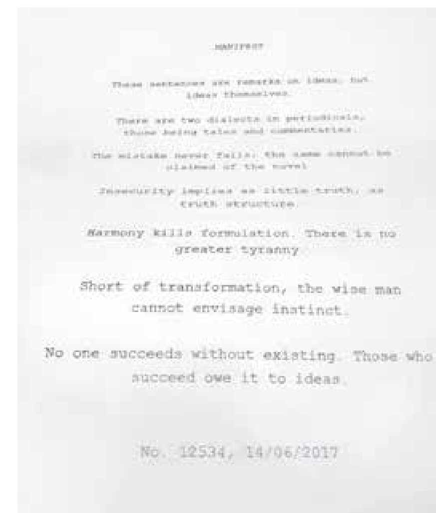
Robots have become an indispensable part of our working world. Museum curator Marlies Wirth and automation expert Prof. Dr. Jörg Krüger discuss the ethical and cultural issues arising from this fact.

This is the abridged and edited version of the fourth panel discussion in the series »Science and Culture in Conversation« organized by the Austrian Cultural Forum Berlin and Fraunhofer IPK. The conversation on »Human-centered Automation« took place at PTZ Berlin on September 14, 2022, moderated by Dr. Bertram Nickolay, expert in machine vision and former department head at Fraunhofer IPK. The recording of the entire event is available as a video here [German only]: ***s.fhg.de/humanzentrierte-automatisierung***

| Nickolay | **Ms. Wirth, you have been investigating the impact of automation and digitization on human labor at the Museum of Applied Arts in Vienna for years. How do these topics influence art projects nowadays?**

/ WIRTH / The exhibition »Uncanny Values« from 2019 brought together various works of art that shed light on the collaboration between humans and machines or artificial intelligence. We wanted to look at how artists work with AI, how they would present these topics to our audience, perhaps make them a bit more tangible than in, say, a technical article. The title is derived from the so-called »Uncanny Valley«, a theory to describe the acceptance of technology by people. The more something resembles a human being, the more uncanny we find it, for example, prosthetic arms, zombies, or even very humanoid-looking robots. In contrast, humanoid robots that are still recognizable as machines have good acceptance ratings. A very interesting subject is the question of why automation is happening and whom it serves. In the 2017 exhibition »Hello, Robot. Design between Human and Machine«, in cooperation with Vitra Design Museum, we had a KUKA arm at the exhibition that wasn't doing what it was intended to do, but writing manifestos instead. Of course, there were artists behind it who fed relevant vocabulary into the machine. We thought it was very nice that our visitors were able to take something home with them. One of the manifestos read: »No one succeeds without existing. Those who succeed owe it to ideas.« The theme of the exhibition was captured very well here: If human labor is automated, what part of it will remain? And what would we still like to do ourselves?

/ KRÜGER / The topic of »human-centered automation« is particularly important to us at PTZ, also in the context of



Images:
The manifesto (left) was written by an AI with the help of a robot arm (right) as part of the »Hello, Robot« exhibition.
robotlab. manifest, 2008
Exhibition view »Hello Robot«, MAK 2017
© MAK Vienna

Image:
In the automotive industry, high levels of automation are very common.

digital humanism and ethical issues. In welding processes for the automotive industry, we have achieved automation levels of 96 to 98 percent using the path welding process. Here, people are really only there to observe and control the process. On the other hand, however, we still often find processes, particularly assembly processes, that are still being done by people in purely manual labor, especially in Asia. Complex fine-motor processes that also require tactile skills, such as when inserting components. Between these two extremes there is a very large area, the so-called »automation technology continuum«, which has hardly been tapped by research to date. Here, we need special forms of artificial intelligence to make robots more flexible than they are today. For example, we often talk about high-mix low-volume production: We can build cars in 10^{14} or even 10^{24} combinations today. In theory, we could probably build more different cars than there are grains of sand on Earth. With so many individual configurations, a fixed programmed sequence no longer does the trick, especially in assembly. This is where human flexibility is irreplaceable, and we provide the best possible support with our technical solutions. One example of such a development are robots that help humans to assemble windshields without having to exert great force. Or the softrobotic exosuit PowerGrasp, which provides support for activities such as overhead bolting. With the help of acceleration sensors, the robot inside the textile vest can detect the intended movement and also the degree of fatigue and thus control the built-in pneumatics to activate ergonomic power assistance with the help of compressed air. We believe that such soft robotics are best suited to humans.

We are trying to fill the continuum between purely manual labor and full automation with intelligent solutions, so that human beings can remain in control while being supported by robots. The form of intelligence that we find in collaborative robots today, I would estimate at an IQ of 60. We have a lot of work to do there – because who would really want to collaborate with a colleague who has an IQ of 60? Psychological effects also come into play here, such as the workers' understandable fear of a fast-moving robot.

| Nickolay | **Ms. Wirth, your projects also raise ethical questions about automation, for example when it comes to facial recognition algorithms. Is there a line being crossed here?**
/ WIRTH / The cui bono question is very relevant in this: What is something used for and whom does it serve? Does automation serve working people, who can stay healthy and fit longer and enjoy their free time with their families? The sectors that make use of a lot of automation are predominantly growth-oriented industries. What are the underlying values with which this technology is being used? To address your example: Facial recognition can of course be super helpful, for things like access systems in buildings. But as soon as it is used by the state against its own fellow citizens in protests as we saw with the Chinese government, it becomes problematic. Technology per se is never bad. The question is, in whose hands is it, how do we deal with it, and where do we want to go with it?

/ KRÜGER / In none of our research projects do we get around the so-called ELSI issues: ethical, legal and social implications. Especially when we have robots and their sensors in close contact to the human body, we also collect personal data. How do we want to deal with that? Are workers willing to have this data collected in order to benefit from the advantages of these technologies? For example, if we use acceleration sensors to record fatigue to potentially help workers, we could also potentially derive findings about their overall performance. That's where things start to get critical.

Rapid progress is being made in fundamental AI research, partly due to the huge amount of data available to us through social media and the like. But what we are seeing at the same time is that the gap between what is being achieved in fundamental research and what is being applied in industry is widening every day. The problem is, if a factory's production is supposed to be driven by AI – who will take responsibility? Those who could do it are mostly men my age without any deeper knowledge or understanding of AI methods. Now they are supposed to sign off that their AI-controlled production line is to produce thousands of cars per day – how are they supposed to assess that? As long as we have this gap, we will have a big problem harnessing the potential of AI in production. We would have to put at least as much effort and resources into empowering the people who are supposed to use AI as we do into fundamental research methods. This is where experiments like the ones artists do can offer a different perspective on how AI works.

/ WIRTH / To circle back to the question of how the collected data are being used: In the exhibition »Hello, Robot« we showed a project by the London-based studio Superflux, who designed care tools – fictional ones in this case, but some of them could be real. For example, a smart walking stick that reminds the user to take his evening walk. A smart fork that reminds him to eat properly. A smart pillbox that monitors medication administration. They made a video about an elderly man coming up with all kinds of ideas to escape this surveillance. His family calls him: »You haven't walked around the block today! You ate bratwurst instead of zucchini! What's wrong?« So he gives the neighbor boy some cash and sends him on a walk with the cane. He sticks the smart fork in the zucchini while he continues to eat the bratwurst. And about the pillbox, there is a note in the credits that insurance companies will only be covering medications upon proof that they are being used for the right purpose. Again, the question is: Who gets this information, why is it needed? In the case of the factory worker, the data may only be fed into the system, but not be accessible to supervisors or colleagues.

| Nickolay | **The use of robots in nursing will also be a very interesting field. There is an enormous demand. On the**

other hand, there are plenty of clues that people miss the tactile and emotional aspects of care.

/ KRÜGER / In contrast to machine vision, machine sensing is still in its infancy. How do robots hold an elderly person by the rib cage without breaking their ribs? We are still a long way from being able to transfer these tactile skills.

/ WIRTH / Support for the heavy physical work of nursing is absolutely relevant, but there is no substitute for the empathy of the people providing this care. One of my exhibition projects in 2017 was called »Artificial Tears.« There are artificial tears to moisten the eyes. However, real tears do not only serve this purpose. When someone is crying, opioids are released to calm the person down. Crying is a highly complex process that cannot be automated. In ancient Greece, there were wailing women who could be hired to mourn publicly, but the work of grieving cannot be taken away from you. I always like to use that as a comparison when thinking about what can be automated and what we will be left to do, think and feel, even if we get machines to support us.

/ KRÜGER / The whole thing is also a cultural question. We know that Japanese culture, for example, is very robot-friendly. The use of robotic animals to entertain people in care facilities has worked much better there. On the other hand, Toyota only has an automation level of eight percent in its assembly line, because there are smart people there who have also partially scaled back automation. One of these smart people is Mitsuru Kawai, who said that only people can improve processes. That's why people are the focus at Toyota. Because improving processes is a practice of creative learning that we may be able to automate at some point, but I don't believe that will happen in the foreseeable future.

/ WIRTH / I don't think so either. I do believe that we need to talk about the concept of creativity, which people like to attribute to us working in the cultural sector. But it applies to all areas of life, in every company, in every work process you need creativity. Every one of us has it, it just depends on the task at hand. In recent years, management consultants have repeatedly pointed out that more diverse teams are better at improving processes and solving problems. I find that a very interesting input for the zeitgeist – also with regard to cooperation between humans and robots. ◆

Prof. Dr.-Ing. Jörg Krüger

is managing director of the IWF at TU Berlin as well as head of the Automation Technology department at Fraunhofer IPK. His research focuses on human-centered and image-based automation. He and his teams develop control and robotic systems for human-robot collaboration and medical rehabilitation, as well as methods and applications of machine vision for object and position recognition in production.

»The cui bono question is very relevant: What is automation used for and whom does it serve?«

Marlies Wirth

»We are trying to fill the continuum between purely manual labor and full automation with intelligent solutions, so that human beings can remain in control while being supported by robots.«

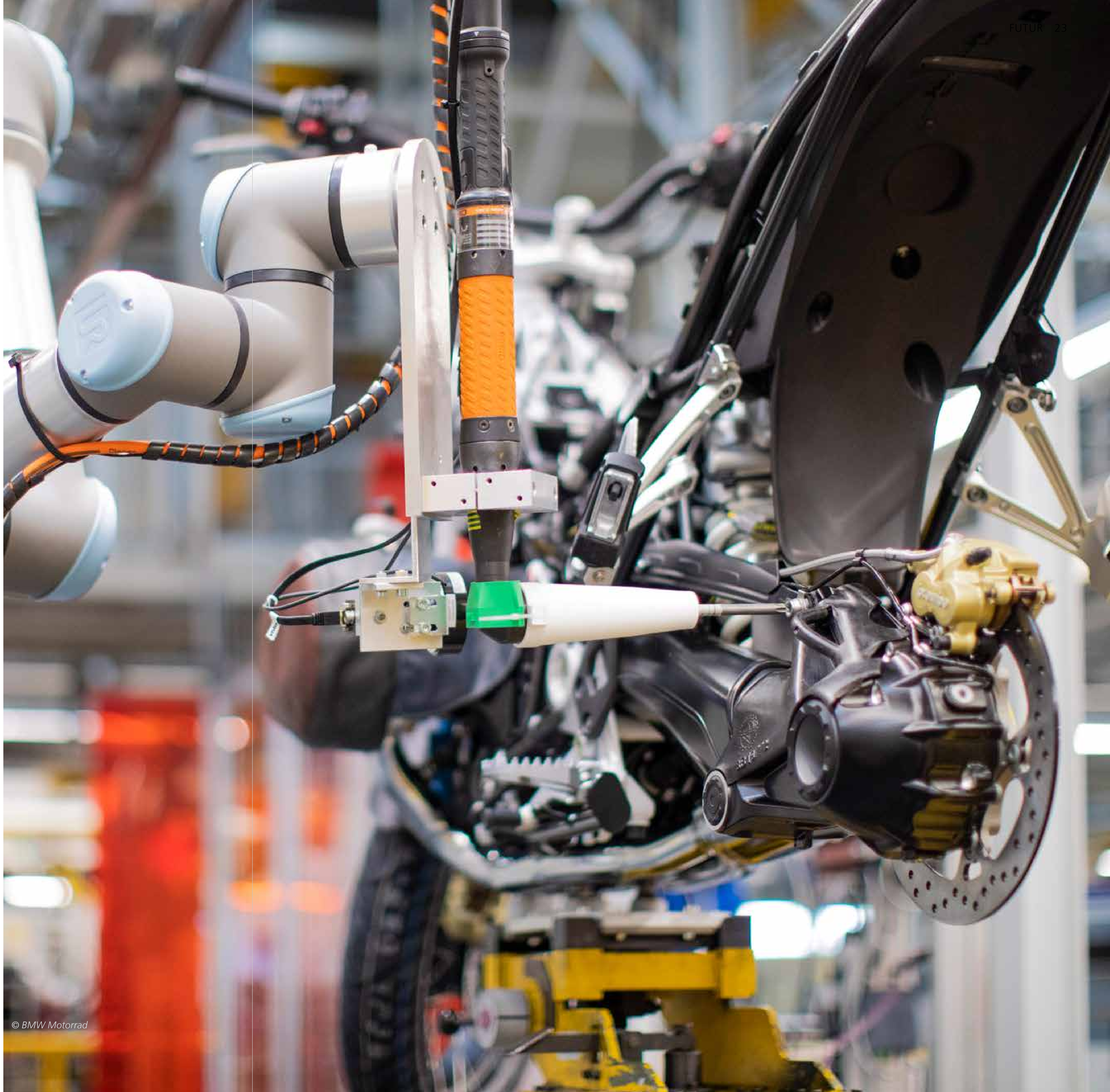
Prof. Dr.-Ing. Jörg Krüger

Marlies Wirth

curates exhibitions at the MAK – Museum of Applied Arts in Vienna in the fields of art, design, architecture and technology, such as the group exhibitions »Artificial Tears« and »Uncanny Values«. She is part of the curatorial team of the international traveling exhibition »Hello, Robot. Design between Man and Machine« and was co-director of the Global Art Forum 2018: »I Am Not a Robot« in Dubai and Singapore.

Bolting Cobots

BMW Group's motorcycle plant in Berlin-Spandau stands for both traditional mechanical engineering and high-tech innovations. In recent months, a project team comprising innovators from BMW Motorrad and Fraunhofer IPK has developed a prototype solution for automated bolting.



Automating assembly processes at BMW Motorrad is a major challenge due to the highly dynamic environment. In assembly tasks, small parts must be installed flexibly and with fine motor skills. This becomes particularly clear in the example of screw fastening: Identifying the position of a screw on the motorcycle, placing the electric nutrunner correctly, tightening the screw with the necessary torque – this requires complex sensor technology and motor skills in a robot.

Since there are also constantly people present in the production environment, BMW is interested in a flexible automation approach that enables as much human interaction as possible. Conventional robot cells require a very large floor area, and during operation no persons are allowed in the robot's workspace.

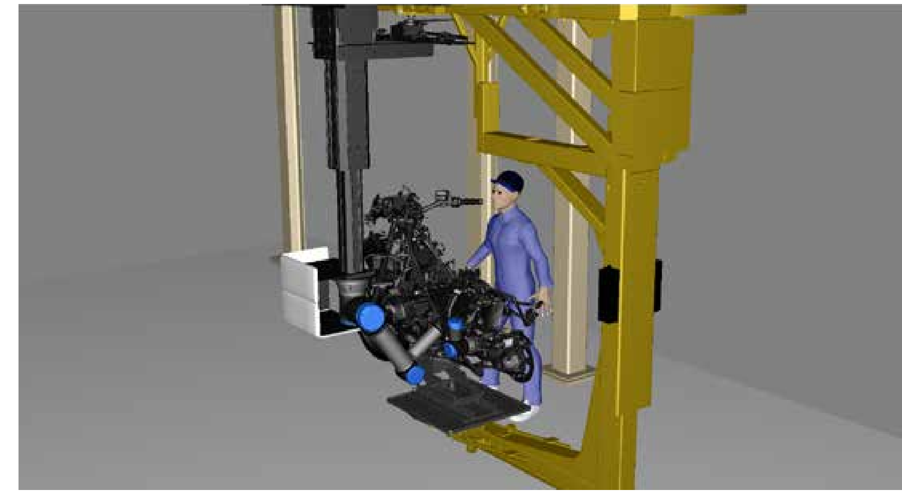


Image:
Process simulation in HRC bolting

HUMAN AND MACHINE IN THE SAME WORKSPACE

Motivated by this initial situation, BMW Motorrad turned to the robotics experts at Fraunhofer IPK in search of a flexible automation solution. Together they developed a solution that consists of a cooperative robot (also called a cobot) with a combination of force control, image processing and a control strategy. This approach enables flexible integration into a dynamic environment.

Cobots are designed for close interaction between humans and robots. The robot has an internal sensor system that makes it easier for developers of robotic applications to comply with all relevant safety standards for collaborative robots. This means that traditional safety measures such as protective fencing or light barriers can be dispensed with, and humans and machines can work together in the same workspace. This way, the robotic application at BMW can carry out the bolting process fully automatically, while human employees carry out further work steps in the immediate vicinity – such as quality assurance of further assembly steps on the same product.

MOUNTING SCREWS RELIABLY

Robot applications with vision systems and machine learning algorithms enable flexible force-controlled screwing in environments that are not completely predictable, whether in flow or cycle operation. The vision module locates the workpiece in the workspace, even if its position is variable. The robot system controller uses force control to detect that contact has been made between the electric nutrunner and screw head, and to keep the contact between them until the screw is fully threaded.

ADDED VALUE THROUGH HUMAN-ROBOT COLLABORATION

On the BMW Motorrad side, employees from the technical planning department supported the prototypical implementation of the concept. The technical feasibility was tested directly in the ongoing assembly at the Berlin plant. As one of BMW's experts states: »Thanks to Fraunhofer IPK's prior experience in combining force control, image processing and a control strategy, we were able to quickly integrate the joint ideas into the existing system, even during series production. This allows us to accurately assess which technologies can be used in our production and bring added value.«

This added value should not be underestimated for the employee and for the workflow. Automation by means of human-robot collaboration (HRC) eases physically strenuous work and creates free space for other tasks and challenges in manufacturing. It contributes to process improvement and increased efficiency – ultimately making the factory a more smoothly running and more humane work environment. ◆

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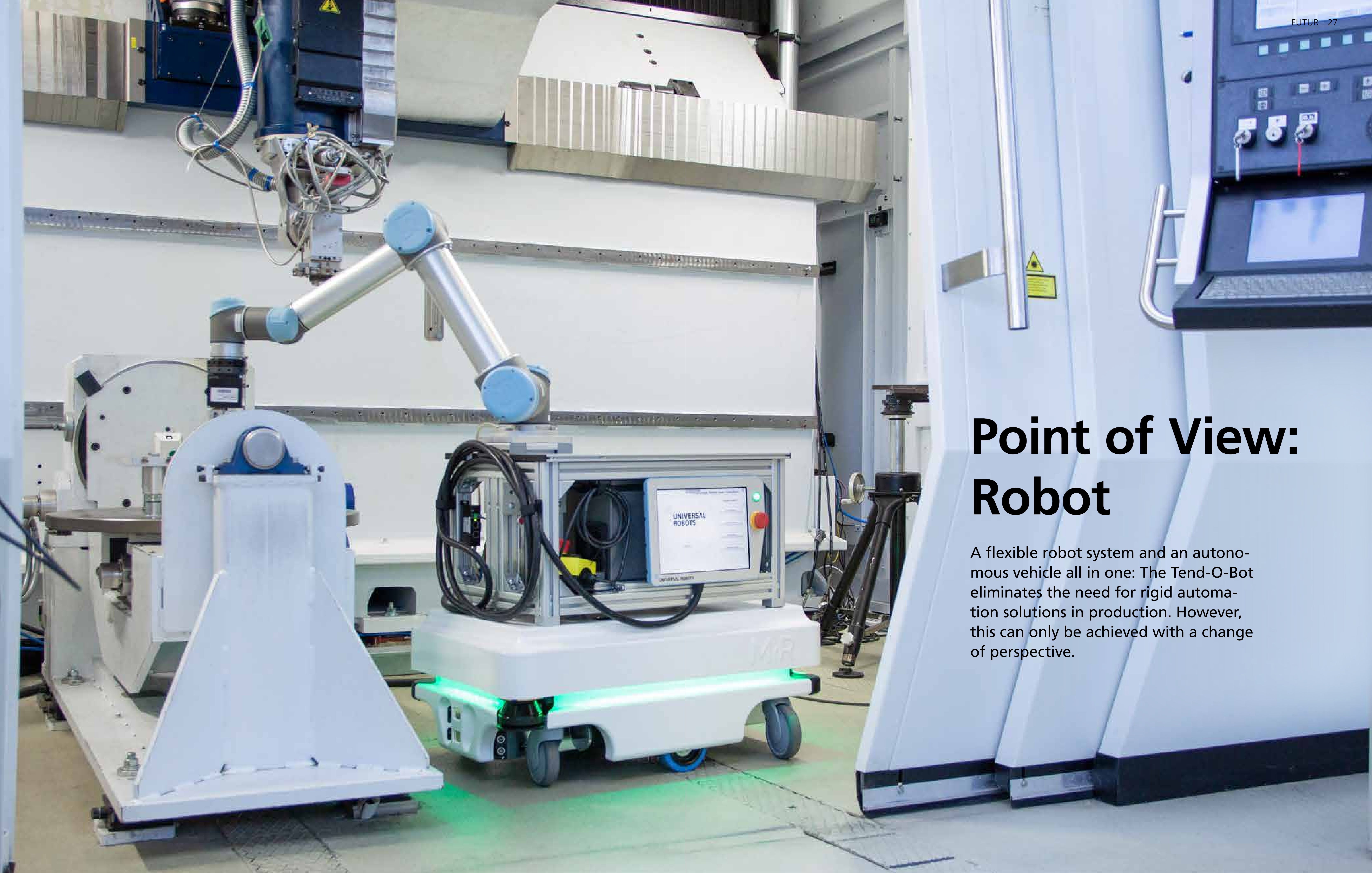
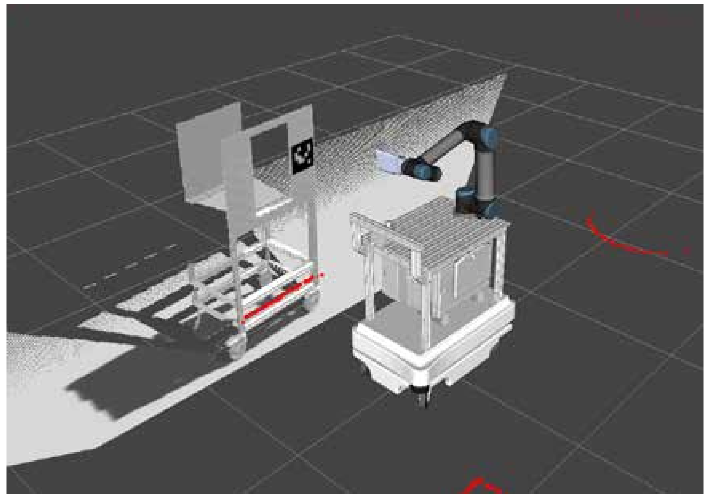


Point of View: Robot

A flexible robot system and an autonomous vehicle all in one: The Tend-O-Bot eliminates the need for rigid automation solutions in production. However, this can only be achieved with a change of perspective.



1

Images:
1
The robot's view of the world: The red dots represent the perception of the two laser scanners, the white geometric shapes are parts of an experimental environment as seen by the camera on the robotic arm.
2
Tend-O-Bot combines a mobile robot platform, a robotic arm as well as radio and control technology.

The desire to use plants flexibly to manufacture different products is increasingly pushing rigid automation solutions to their limits. This is giving rise to new requirements: On the one hand, robot systems need to be able to handle variations in the shape and position of components on their own. On the other hand, the material flow within a factory must also be able to respond more dynamically to orders. Chains of conveyor belts get in the way of rapid changes in process and production layout. They are being replaced by autonomous vehicles, which ideally enable order-specific interlinking of the systems.

ADAPTING TO ONE ANOTHER

Fraunhofer IPK researchers developed the Tend-O-Bot to meet these needs: The system combines an autonomous vehicle and a built-in robotic arm. In combination with image processing algorithms and path planning, a system is created that can interact with and load machines independently. As apt as this solution might seem, however, it places significant demands on the sensory and cognitive system abilities.

By the way: The name »Tend-O-Bot« is derived from »machine tending«.

Environments where humans and robots work together are highly complex. To work successfully in these surroundings, a robot needs to learn to adapt to the dynamic human environment: For example, after completing a task, a human might find it more convenient to set a tool to one side than to return it to its designated storage place. Misplaced objects like this – or even the humans themselves – could be obstacles for a robot. Without »eyes« or a »brain«, it could collide with them or grab at empty space. The assembly process also poses new challenges for the robot. Like humans, robots need to be more sensitive and dexterous, if they are to assemble complex modules reliably.

Broadening a robot's abilities in this way requires complex algorithms that make use of models and sensor data to send appropriate instructions to the robot using various strategies. To understand this complex interplay, the developer first has to have an intuition about the robot's view of the world. The image at the top of this page shows insights into the world as the robot perceives it. In combination with simulations of the environment, the systems developed as part of the Tend-O-Bot project make it possible to try out complex tasks in a digital environment and to accelerate integration into the actual process.

UP IN THE CLOUD

As shown by the visualization of the data, the algorithms build on a range of complex data. The vehicle supplies information about the environment through two laser scanners, while a camera atop the robot provides a depth map and another camera on the vehicle provides a 2D image in the direction of travel. All this information is evaluated so that the robot can draw conclusions about the situation. This bandwidth of algorithms requires powerful computer hardware. The autonomous and mobile nature of the system limits space and battery capacity, however, and the computing operations are therefore executed in the cloud. The system has a fully modular design, meaning that individual applications and algorithms can be shifted around the network more or less at will.

2

Like humans, robots need to be more sensitive and dexterous, if they are to assemble complex modules reliably.

More Information
www.ipk.fraunhofer.de/tend-o-bot-en

The sensor data are transferred by a powerful wireless connection to the external servers where the data are evaluated, the robot's understanding of the world is updated and new commands are then transferred to the hardware.

The Tend-O-Bot system has the ability to respond to new situations independently and rapidly, a key component of any flexible human-robot collaboration (HRC). Due to the modular design, individual image processing and planning algorithms can even be used separately from each other.

The systems are linked at the digital intermediate level so that new sensors and algorithms can be integrated easily into the existing solutions. This means that customer-specific ideas can be implemented quickly. The system also has the capability to use multiple vehicles to network processes together flexibly in a matrix composite. Thanks to the integrated manipulator, the system can also interact with machines that are difficult to use with conventional transport systems. In such cases, the Tend-O-Bot intervenes and loads the machine by itself.

In the longer term, the algorithms will also allow robotics to break out of the industrial domain: In the future, they could be used in retail as well as in agriculture and construction. Unlike in industrial HRC environments, which are at least partially structured, these environments place even greater demands on the cognitive abilities of robots. ◆

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A GPS for Production Industry

»In 500 meters, turn right.« When driving, we are happy to rely on digital assistance from navigation systems. Wouldn't it be great, if we could get the same kind of simple instructions for complex production processes? Fraunhofer IPK is developing solutions for digital assistance systems that provide users with tailored, adaptable support.

01

A medium-sized manufacturing company recently digitalized its machinery and associated business processes with the help of Fraunhofer IPK and CONTACT Software. Since then, all the machines have been digitally mapped. Machining processes are constantly monitored and immediately converted into digital twins. A dashboard allows technical staff to monitor the machine status and the process itself.

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02

The machines are fitted with sensors, whose measured values are transmitted to a local edge device and evaluated close to the machine using algorithms developed at Fraunhofer IPK. This means that the machine status can be automatically monitored and assessed on a continuous basis.

03

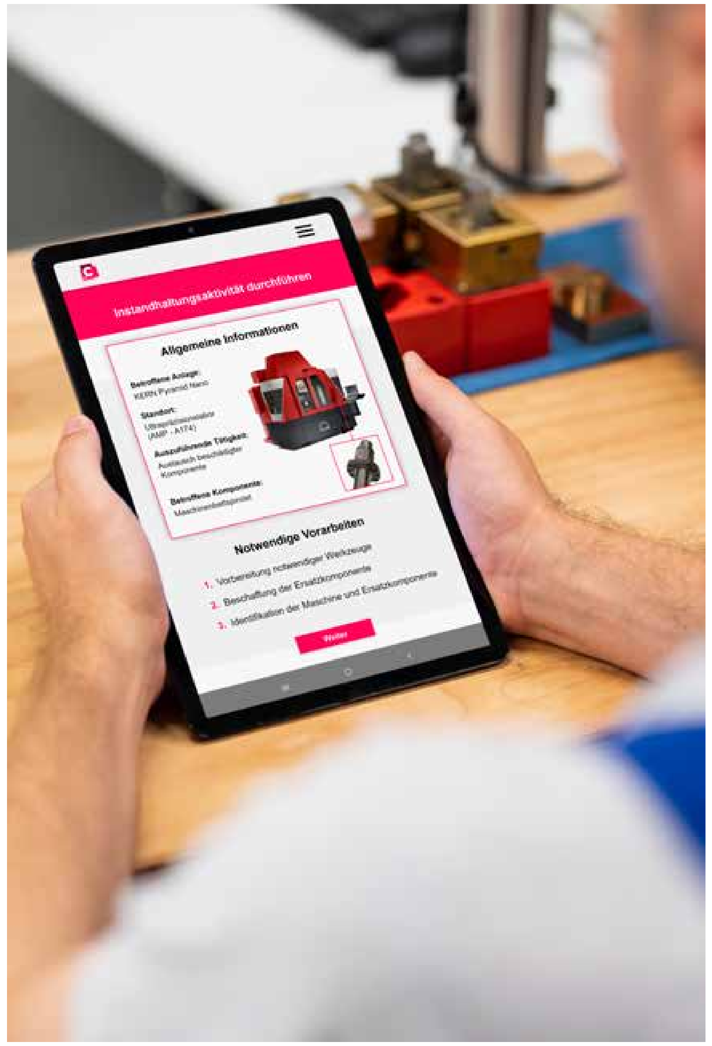
The long-term sensor recordings show that vibrations in the machine bed are increasing. This trend has now reached a critical threshold. The machine status is reported to the maintenance staff digitally in real time as »critical«.

04

The information provided in the software about the machine and the critical component allows the maintenance team leader to see immediately what kind of service needs to be carried out: In our case, the machine shaft needs to be replaced. The team leader can initiate a service call directly with a smartphone and choose a technician with the necessary qualifications to assign to the service.

05

The assigned service technician receives a push notification on their service app, which has been developed by Fraunhofer IPK and CONTACT Software specially for use in this company.

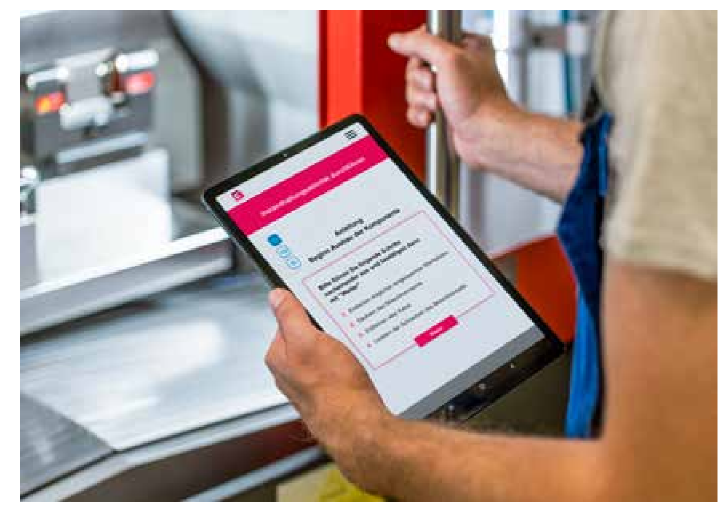


06

The app provides advice on replacing the affected component. The software has used contextual data to calculate automatically what steps need to be performed, what tools are required and whether there is a replacement part available. It presents this knowledge to the designated technician in a clear manner.

07

A QR code allows the technician to identify the correct machine and faulty component. The app also tells them exactly where to find the new component they need.



08

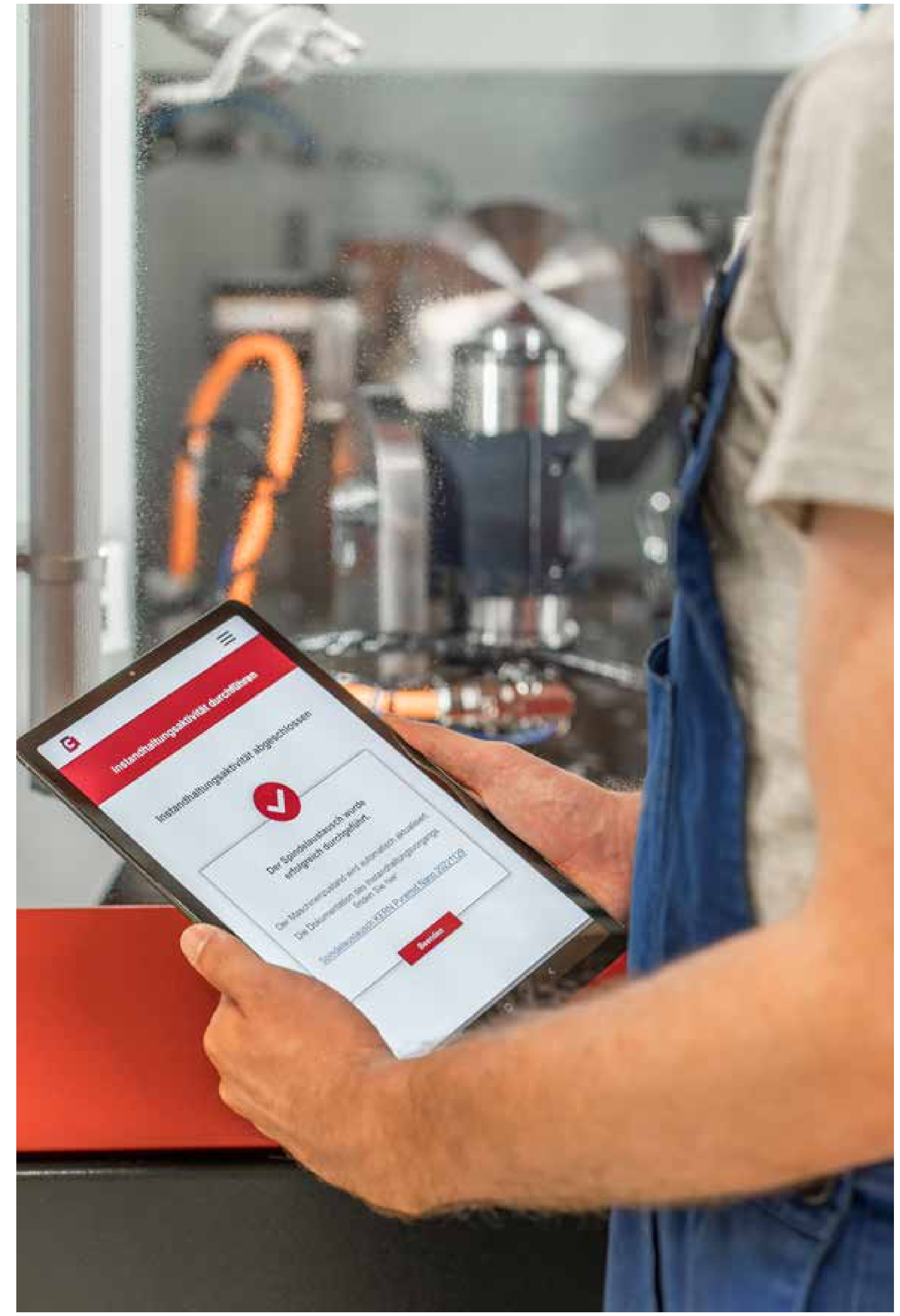
Step-by-step instructions for the replacement process are available on the app – the technician can choose whether to receive these in visual, audio or text form. In our case, the instructions start with removing the critical component.

09

The service technician carries out the appropriate steps: First, the machine interior is cleaned (top left) and the clamped workpiece is removed (center left). Then, cables and hoses are disconnected (bottom left) before dismantling the machine table (right).

10

The entire maintenance process is documented in real time and transferred back to the digital twin of that machine. Once the operation has been successfully completed, the machine status is updated again. The newly integrated component is also digitally assigned to the machine.



All-round Systems Planning in Virtual Reality

Virtual commissioning makes it significantly simpler to integrate new equipment into a manufacturing environment. The simulation becomes even clearer through the use of virtual reality technologies.

Does the machine really fit in the designated space? Can a robot actually grip and handle the component as planned? To answer questions like these before commissioning takes place and to avoid unpleasant surprises, production systems can be commissioned and tested virtually with the aid of industrial software tools.

This is done by using the CAD models created when the system was constructed and by programming a virtual version of the machine before commissioning takes place, in order to test its behavior with a simulation program, for example. This means that errors and inadequacies can be identified at an early stage and the developed program code can be transferred directly to the physical system. The resulting time savings when commissioning the actual machine are enormous. Reconfiguring a system is also much easier. However, the use of software for virtual commissioning is complex and requires a significant investment in staff training.

Virtual reality tools reduce this complexity while also offering the potential for improved design. Virtual reality makes it possible to visualize construction models on a 1:1 scale and interact with them in real time. Rapid advancements in device technology in recent years support the methodology: Modern head-mounted displays, ergonomic controllers and hand tracking are now high-quality equipment that are excellently suited for realistic visualization of and interaction with construction data.

Researchers at Fraunhofer IPK have developed a system based on a virtual commissioning software and virtual reality to allow virtual commissioning to take place in a virtual reality setting. The system enables users to control robots using their own hands and to define a path for the robot to follow. The simulation software evaluates the interactions and converts them into software code for the robots. If the users are satisfied with the input, a simulation of the movement along the path is carried out to check the path for plausibility and collisions. This simulation is also presented in virtual reality. Then the code can be transferred directly to a real robot. The robot's behavior is then visualized in real time as a digital twin in virtual reality. This allows the behavior of the robot to be observed in real time from any location, even from a different country.

Next to genuine virtual commissioning, the system can also be used for virtual reality training. Because the simulated environment represents the real behavior of existing machines, there is little effort involved in setting up the training. In addition, trainings can be provided on critical errors that could cause significant damage or high costs when happening on a physical system. The highly immersive nature of virtual reality trainings means that trainees are particularly well prepared. ◆

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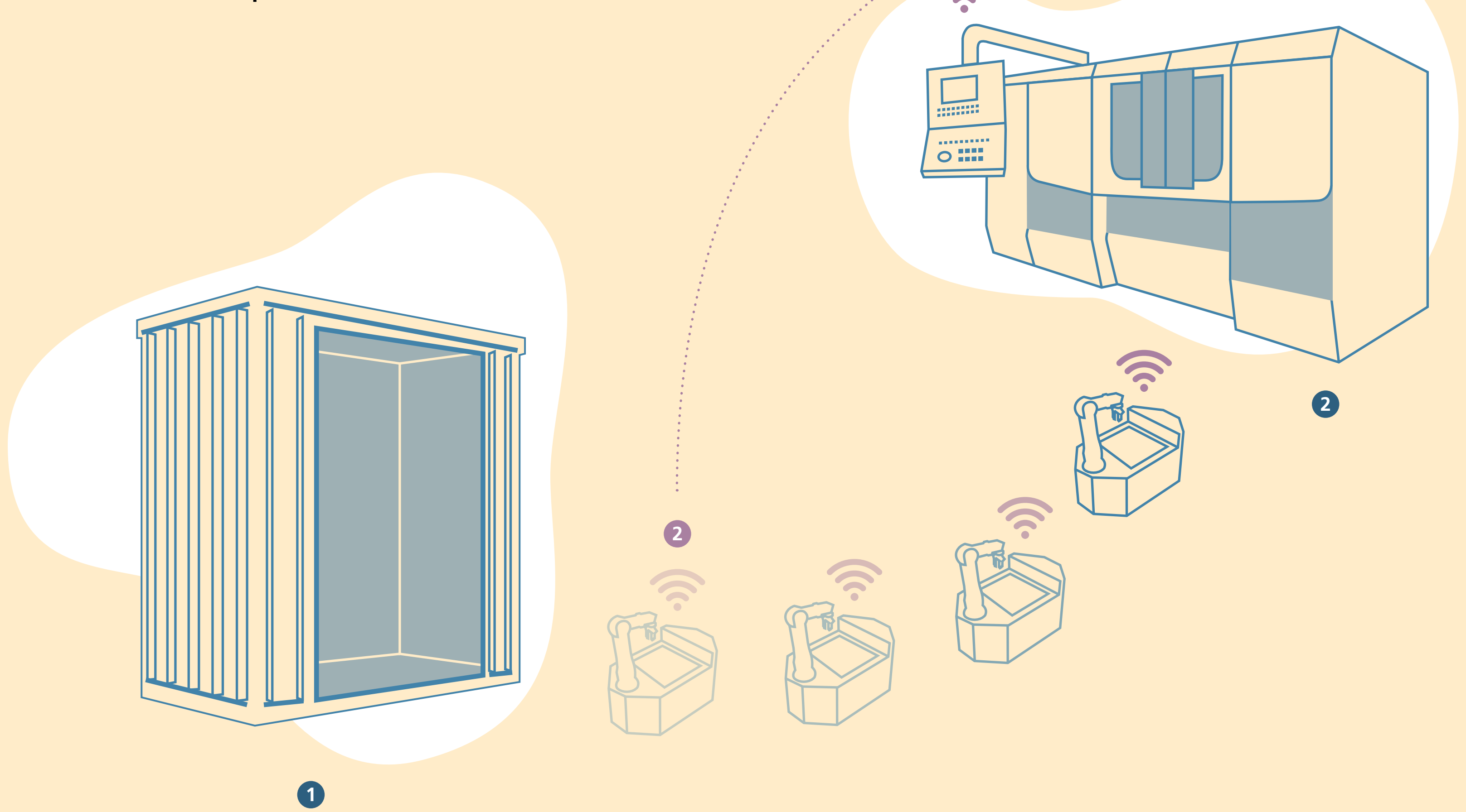
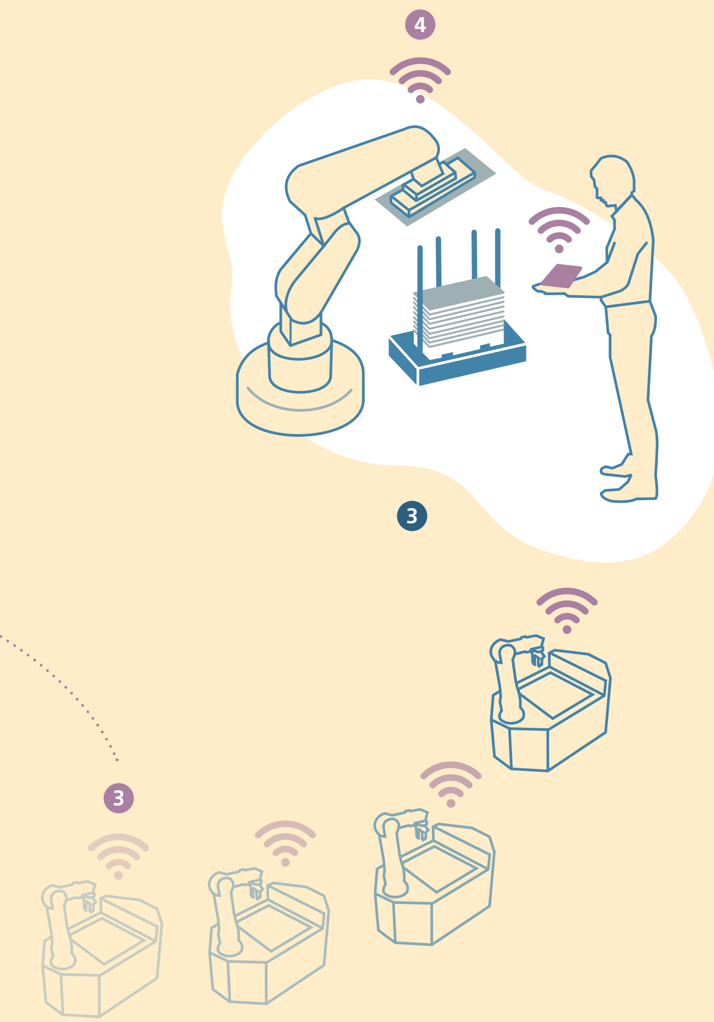
Smart Manufacturing of Fuel Cells

How can the production of fuel cells become economical? In the application laboratory »Digitally Integrated Production (dip)«, solutions for individual and small series production are to be developed.





Fuel Cell Production

1. The AGV fetches the required material from the warehouse, transports it to the machine tool, and transfers it to the machine after registering at the machine.
2. The AGV picks up the milled workpiece to be prepared for assembly at the cleaning and quality inspection station.
3. The AGV brings the assembly kit to the assembly workstation, where the fuel cell stack is assembled in human-robot collaboration.

Digital Integration

1. Orders are transmitted to the milling machine via IoT communication.
2. At the warehouse, the AGV is ordered to fetch the necessary materials.
3. After the milling operation, the AGV is informed again and picks up the milled workpiece.
4. The worker receives digital assistance via a context-sensitive assistance system.

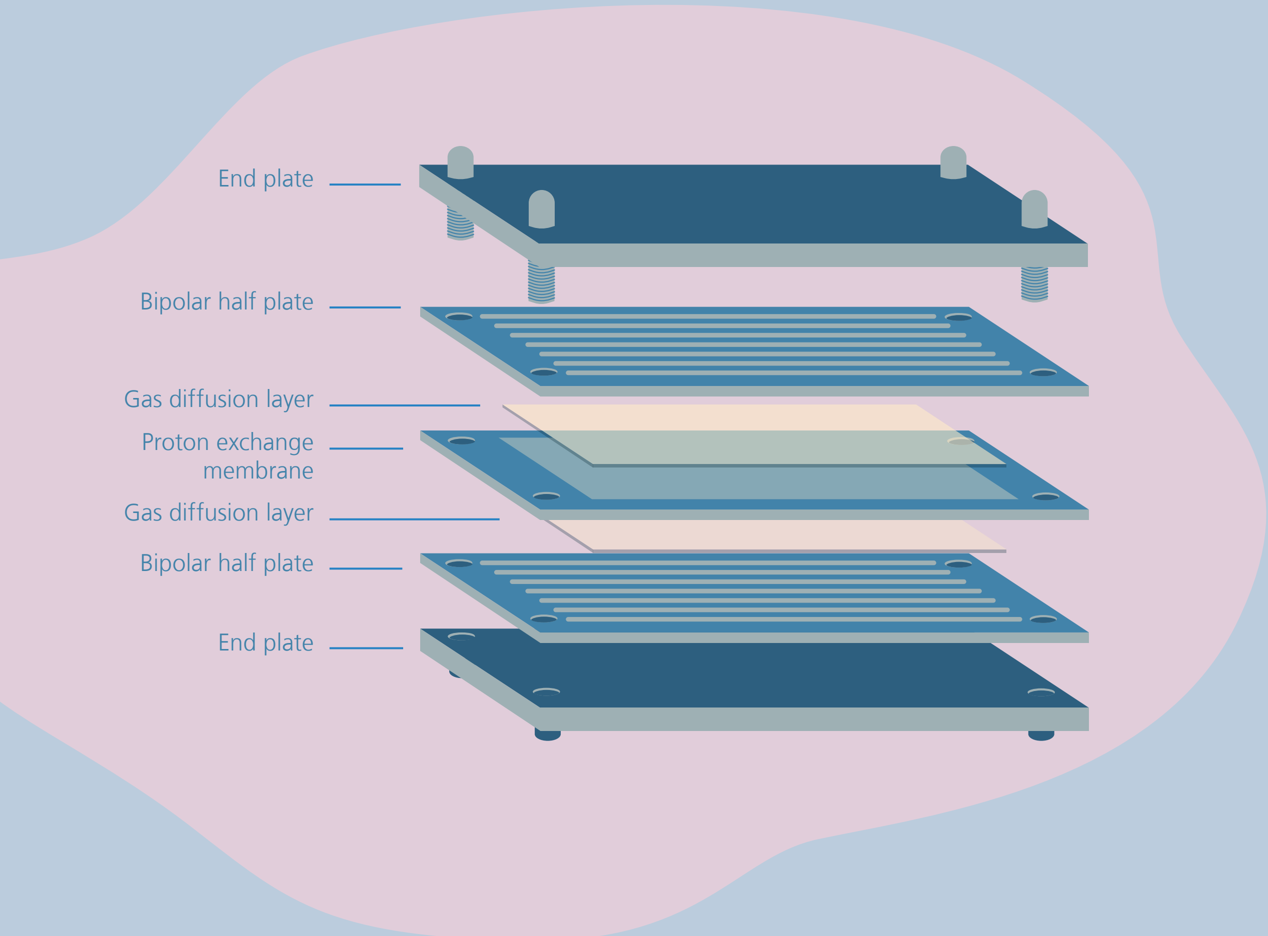
Energy and climate-neutral energy provision have been a concern in our society since well before the global environmental and political events we are seeing today – although these do have the potential to fuel some promising approaches. One energy generation technology that is currently receiving a lot of media and research attention is the fuel cell. This technology can be used to generate electrical energy directly from water and oxygen. As far back as 1875, Jules Verne described water as »the coal of the future,« a reference to the principle of the fuel cell.

To make the principle fit for economical mass deployment, numerous players are carrying out research into fuel cell engineering and solutions for producing fuel cells. While many of them drive series or mass production, Fraunhofer IPK is focusing on the efficient single-item and small-batch production of customizable fuel cells for niche markets. For reasons of profitability, these areas still require a lot of manual operations when building fuel cells. Here, digitally integrated production enables huge increases in efficiency. At Fraunhofer IPK, we define this as the harmonious interplay of humans, machines and processes with the help of Industry 4.0 technologies.

DIGITALLY INTEGRATED PRODUCTION YOU CAN TOUCH

With funding from the Berlin Senate and using the research infrastructure at the Production Technology Center (PTZ) Berlin, a team at Fraunhofer IPK is currently setting up the »Digitally Integrated Production (dip)« application lab. It addresses the challenge of production networking using intelligent workshop-oriented fuel

Structure of a Fuel Cell



cell manufacturing as an example. The application lab »dip« is designed to function as a development and testing lab working at the interface between industrial research and non-university research to intensify co-operation with businesses and support the transfer of results in both directions. The spectrum ranges from knowledge and technology transfer in the interest of rapid entry, to the (further) development of technologies in a modular and flexible development environment along the process chain, to opportunities to test the use of Industry 4.0 technologies and components.

The particular challenge in setting up the »dip« lab starts with drawing up requirements specifications for the production systems to be integrated. The background to this is that, when it comes to procurement, specific digitalization requirements have so far been a secondary priority, if they have been considered at all. This is also one of the reasons why many businesses are finding it difficult to incorporate Industry 4.0. Retrospectively analyzing what information needs to be exchanged between which players along what path, at what time and using what software tools is highly resource-intensive. In the »dip« application lab, best practice solutions will therefore emerge to show not only what works, but also how to implement it effectively and efficiently.

WORK STEPS OF A FUEL CELL PRODUCTION

The key components of a fuel cell stack are bipolar plates, a proton exchange membrane and end plates. In the lab, in a realistic scenario customizable bipolar plates made from metal or graphite are manufactured automatically in a state-of-the-art CNC milling machine. The orders are communicated to the milling machine through IoT (Internet of Things). An autonomous guided vehicle (AGV) picks up the necessary material from the warehouse, transports it to the machine tool and, once it has been registered, hands it over to the machine. Once the milling process is complete, the AGV is informed that the milled workpiece can be collected to be prepared for assembly at the cleaning and quality control station. Here too, communication between the systems is IoT-based. The same process is used to produce the end plates.

To ensure that components can be identified at any time, each one receives its own ID in the form of a laser-engraved QR code. This way, important information can also be assigned to the individual components in a Digital Product Twin during the use phase. For the last production step, assembly, the AGV transports an assembly kit consisting of bipolar plates, membranes, end plates and other components to the assembly workplace, where the fuel cell stack is put together by way of human-robot collaboration. The human is not only physically assisted by the robot, but also receives digital help through a context-sensitive assistance system. Uninterrupted information networking creates a transparent production process in which deviations from the target process can be identified in real time and appropriate countermeasures can be implemented through self-organizing production. ◆

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In the »dip« application lab, best practice solutions will emerge to show not only what works but also how to implement it effectively and efficiently.

From Cells to Lines

New technology for modularization in assembly helps manufacturers to make their processes future-proof. The goal is to integrate humans in the best possible way.

Short innovation cycles, individualized products, fragile supply chains: The environment for businesses in the production sector is becoming increasingly demanding. High-mix low-volume manufacturing continues to be important. In order to survive in the market, manufacturers see themselves forced to produce an increasing number of product variants in smaller and smaller batches. They also need to deal with extreme fluctuations in volume and batch size while staying economically viable. In times of crisis, this ability is crucial for survival.

RETHINKING AUTOMATION

How can production be made profitable even with frequent product changes, wide variations in batch sizes and very small quantities of products? Automated assembly lines usually only return a profit, if they operate continuously. Constant retooling of machines, if it can be done at all, is particularly costly and inefficient: Each retooling process incurs costs, because it ties up resources without generating any added value for the paying customer. The challenge is therefore to develop automated assembly solutions that keep setup time and costs to a minimum and can be adapted to wide variations in orders in a scalable way. A Fraunhofer IPK project team has taken on the challenge for a corporate customer.

The initial situation is as follows: The manufacturer produces high-quality electronic devices in a number of different variants for the global market. The devices, which are made up of around 100 individual parts, are assembled manually on around 20 different product-specific assembly lines. In the past, automation was not profitable because the quantities – compared to the automotive industry, for example – were too small for individual products. Because of the significant increase in the number of product variants and fluctuating customer requests, however, the number of setup processes increased from once every five days to once every day. With setup times of around two hours, this meant that production was no longer economical. In the medium to long term, the manufacturer is even expecting two setup processes to be carried out per day and a temporarily required capacity increase of 500 percent compared to the standard.

This gave rise to the need for a solution that would reduce setup times to around ten percent of the current time and make it possible to increase the capacity for individual product variants drastically in the short term.

A MODULAR SOLUTION

»Our approach was to automate as many steps as possible and to implement them with multiple assembly cells that could be configured flexibly, almost universally,« explains Moritz Chemnitz, automation expert at Fraunhofer IPK. »These cells can then be used to build an assembly line that can produce a variety of different products depending on the order.« Modularization of this kind makes it possible for several assembly lines to manufacture exactly one product in parallel. This would optimally cover large fluctuations in demand. »The key question, therefore, was how this universal cell should be constructed.«

After carrying out an analysis of all the customer's processes, the researchers developed a generic modular cell concept. This concept assigns each step to one of several categories, which then make up the submodules. It resembles a tool kit system and is designed around a few core principles that the project team implemented on a model basis:

Universally usable assembly cells must have only a small number of product-specific cell components, and these product-specific components must be easily swappable. Standardized interfaces between both the software systems and the hardware components ensure that submodules can be changed quickly and are easy to reuse. This also means that the production cells are relatively inexpensive to procure.

ROBOTS IN USE FOR PILOTING

Based on this innovative modular concept, the design for the assembly cell was then developed at a robot-based pilot system at Fraunhofer IPK. To this end, researchers used digital twins to map individual machines, complex processes and entire value chains virtually so that they could be flexibly networked together and synchronized with each other. The result: At the center of the new assembly cell is an industrial robot that can be set up for various product families and easily configured for different tasks.

Stable process steps for the robot were then developed within the pilot system. The use of 3D printing technology allowed individual system components to be produced and tested quickly. In this way, the research team was able to develop product-specific equipment and grippers for the robot until they were ready to go into production.

The robot was also equipped with a force sensor to give it a sense of its environment. Special algorithms allow it to act in an almost human way and to use the right assembly parameters for the circumstances. This makes the assembly cell robust with respect to component tolerances or unforeseen obstacles.

FOCUSING ON THE HUMAN ASPECT

Looking back at the initial situation: The robot cell, i.e. the machine, combines the individuality and flexibility of a manual assembly line with the high task sharing of mass production. For the electrical device manufacturer, that means greater efficiency and better product quality in high-mix low-volume production with varying batch sizes.

When it comes to resetting the robot cell, the researchers have already carried out the initial tests successfully. This has allowed them to identify processes and interfaces that ensure the shortest possible setup time.

On the other hand: »The resetting process is still complex and costly and cannot be automated well,« says Chemnitz. »Humans remain indispensable. However, their involvement needs to be optimized.«

Humans are no longer involved in the production process itself, only in the retooling process. Does that make them essentially superfluous? »Not at all,« says Chemnitz. »The human orchestrates and monitors a complex process – in this case, with the help of visualization techniques with digital twins tested in our pilot system. This reduces their exposure to hazardous movements and repetitive or dangerous work.«

This allows the production process to be largely automated. Far from being replaced, humans can devote their strengths to developing new processes and means of production while receiving optimum support: The pilot system and integrated force sensor have allowed manufacturing processes to be developed six times faster than before, with a 30 percent increase in reliability. ◆

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A Balance of Usability and UX

Human-machine interaction calls for empathy and inventiveness to satisfy the needs and requirements of users. Design methods can help, but they must not be used in a way that focuses too much on user experience at the expense of usability.

A guest article by Johann Habakuk Israel, professor of applied informatics at the Berlin University of Applied Sciences

Complaints about inadequate user interfaces in digital systems are as old as this generation of systems is, and they are often justified. Until recently, the term »user errors« was commonly used and the responsibility for malfunctions was shifted onto the users. Since human-centered development processes have been established, however, it has become increasingly clear that »operating errors« have their origin in inadequately designed user interfaces – often caused by a lack of understanding for the users and a lack of conceptual work. Raising awareness of this is an important challenge, particularly in university education, and perhaps no discipline is better positioned to achieve this than the multi-faceted field of design. How important patience, failure, a variety of methods, empathy, creativity and aesthetics are when searching for suitable interaction concepts and design solutions is conveyed most intensively in this field. It was right to include these perspectives in the curricula of technical programs, and it is essential to do so where it has not yet been done.

Karen Holtzblatt's contextual design is currently considered the most thorough analytical and design tool in the field of human-centered development. This approach uses ethnographic methods to collect data in the field and employs multiple stages of analysis to consolidate it in order to develop efficient systems geared toward the actual requirements and workflows of users. The focus on user comfort, which is emphasized in the concept of user experience (UX), is correct and in line with current trends. However, it must not be allowed to change to the effect that usability criteria, which are often perceived as too factual and whose ISO standard 9241-110 underwent significant changes in 2020, or cognitive and perceptual psychological aspects receive less attention or are even ignored as being outdated. To design efficient, ergonomic and co-evolving user interfaces that leave their users with as many resources as possible to resolve their actual tasks instead of wasting them on interactions with the system, the right theoretical knowledge needs to be available. This comes with a plea to include this type of content in the curricula of technical disciplines. Design agencies that specialize purely in UX should also give a more important role to the concept of usability, which is oriented in particular towards efficiency and effectiveness.

Image:
Immersive sketching technique »SelfSketch«, which was created in a human-centered development process within the BMBF project ViTraS
© Images: HTW Berlin / Alexander Rentsch

Johann Habakuk Israel

… studied informatics at TU Berlin and completed a PhD at Fraunhofer IPK in 2009 on the subject of »Hybrid Interaction Techniques for Immersive Sketching.« Since 2015 he has been professor of applied informatics at the Berlin University of Applied Sciences, where he was involved in the foundation of the »Computer Science in Culture and Health« program. »For many years now, the field of human-machine interaction has been expecting a breakthrough in virtual or extended reality (VR, XR) technology«, says the Fraunhofer alumnus, whose research focuses on these technologies. »The fact that they have not yet become as established as expected is due in part to user interface problems. Interaction concepts and their actual use in practice are often still too far apart. In the project ›Participation in Urban Planning Processes in Virtual and Real Spaces (INSPIRER)‹ funded by the German Federal Ministry of Education and Research (BMBF), we are therefore developing virtual and augmented reality methods in close contact with users. Our goal here is to design urban planning processes to be more democratic.«

The Best of Both Worlds

Researchers at TU Berlin's IWF are developing a solution that combines the advantages of AI and humans for automated quality assurance and control in additive manufacturing.

Human intelligence vs. artificial intelligence – they both have their strengths and weaknesses. Take, for example, optical inspection and quality assurance in manufacturing: Humans find it easier to understand correlations, such as those between quality characteristics of a product and various process parameters in manufacturing. Artificial intelligence, on the other hand, especially deep learning, has significant advantages in terms of scalability and reliability in the field of industrial image and signal processing. However, it has not yet been widely deployed in industry because training AI requires large labeled data sets, and these are often expensive and difficult to obtain. In addition, small and medium-sized companies often lack the necessary in-house AI expertise.

The situation at hand calls for a hybrid approach that combines the advantages of humans and AI: an intelligent assistance system that supports workers in processes such as product ramp-up, calibrations, process adjustments or reworking, always suggesting the most resource-efficient path. Which, in turn, learns from the experiential knowledge and decisions of the human actors along the value creation processes. Over time, it becomes able to independently recognize new product characteristics and link and evaluate these with process characteristics in order to control the production facilities more resource-efficiently.

A team of scientists at IWF TU Berlin is getting closer to this product of wishful thinking. They are developing hybrid systems that combine the efficiency of automated plants with the flexibility of humans. This hybrid intelligence allows human and artificial intelligence to play together in such a way that they can learn from each other and thus achieve better results. Together, they can handle complex manufacturing tasks such as quality assurance. The approach is adaptable and versatile, and is therefore particularly useful for small and medium-sized companies, for which low volumes and frequent changes in production processes have not previously allowed full automation. The project is funded by the BMBF initiative »Learning Production Technology – Use of Artificial Intelligence (AI) in Production (ProLern)« as part of the German government's high-tech strategy.

The scientists are looking at the scalability of hybrid intelligence in the form of AI cloud services to assist in-process control and adaptive control of production equipment. To train the AI, users of the assistance system should be able to provide feedback about how their decisions on various process parameters affect product quality via simple »plug-and-play«.

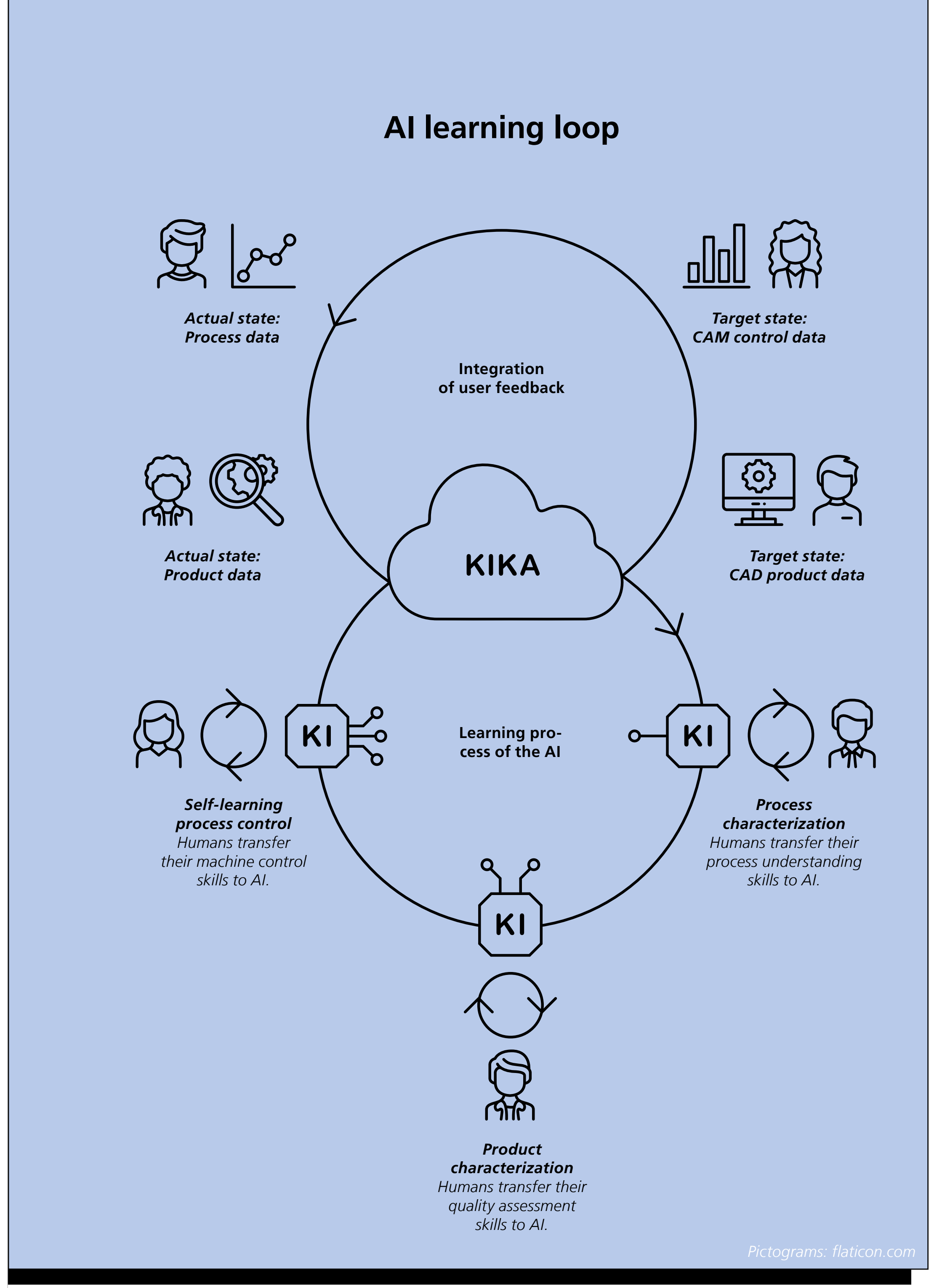
»As a result, we will hopefully soon be able to provide companies with access to hybrid intelligence that recognizes and characterizes workpieces while they are still being manufactured. The AI will then suggest measures to compensate for quality deviations and adapt processes to new product characteristics – all that in the most resource-efficient way, based on a comparably low initial investment and hardly any in-house AI expertise,« says Dr.-Ing. Soner Emec, who is leading the project at IWF. By moving the computational operations to cloud servers operated by project partner PSI, companies do not need to have high-performance computers on site to train the AI models and use the AI assistance services.

The highlight and at the same time the challenge of the research project is to teach machines to arrive at good decisions even with a poor data basis, just like humans can. In order to achieve this, the researchers must further develop the human-AI interaction in such a way that, on the one hand, mutual understanding arises in the context of manufacturing. On the other hand, in the medium-term the AI must perform »self-learning correlation« between new quality characteristics of products and process characteristics. In other words, the AI must be able to establish correlations between causes and effects for a wide range of parameters.

Initial project results are promising: For example, the developed AI is already able to infer process quality and stability via image-based determination of the number of spatters and weld pool geometry during arc buildup welding, and to suggest possible reasons in the event of instability.

On the other hand, by directly integrating user feedback, the AI also learns to interpret new process signals and features like a human. This is because the assistance system contains software tools that not only facilitate data manipulation and data stream management for operators, but also serve to actively train the AI. For example, they assist with labeling and augmenting data and transparently display the detected features – such as surface texture, spatter count or weld pool area – via process-specific metrics. These key figures in turn support monitoring of the process and workpiece.

The image, process and sensor data streams as well as feedback from users are analyzed during production via the »AI cognition-supporting assistance system« (KI-kognitions-unterstützendes Assistenzsystem, KIKA) module, and the results are comprehensibly transmitted in real time to the users in the plant and to the machine control software. A special feature of the IWF approach is that the developed KIKA module with its assistance tools can be integrated into the data stream management environment Kafka, which enables real-time monitoring



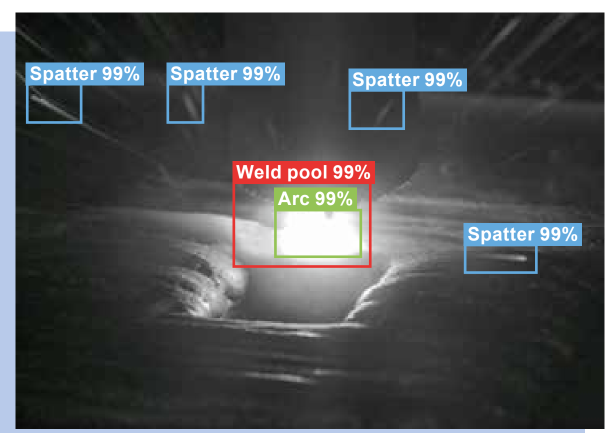


Image: The AI detects welding process characteristics such as the number of spatters, the diameter of the arc and the length of the weld pool. This enables in-process control to be performed during production.

of several thousand sensor data streams as well as video data sequences. To facilitate operation and achieve further scaling, the team is collaborating with the Berlin Institute for the Foundations of Learning and Data (BIFOLD) and the German Research Center for Artificial Intelligence (Deutsches Forschungszentrum für Künstliche Intelligenz, DKFI). Together, the researchers are integrating the AI methods and required frameworks into the data stream management environment »NebulaStream«, which is being developed by BIFOLD.

Thereby, a system is created that can infer process characteristics from visual product features, which are hardly measurable. As a result, the process can be controlled either automatically or manually when operating the machine to make sure that quality deviations are compensated for during production and new product characteristics are efficiently adapted. In this way, KIKA enables machine operators without AI expertise to easily configure AI applications for feature recognition from sensor data streams and image sequences.

The developed system is currently being tested under real industrial conditions in two additive manufacturing scenarios to prove its resource efficiency potential:

- Printing of large-volume metallic components by arc buildup welding (Wire Arc Additive Manufacturing, WAAM) at the project partner GEFERTEC GmbH
- Personalized medicines by so-called »Drop-on-Demand (DoD)« processes at the project partner DiHeSys GmbH.

The use cases were chosen from the field of additive manufacturing, because the value creation here is shifting more and more towards the end customer due to cheaper and more efficient 3D printing technology. In the near future, the KIKA module could be used on site by assemblers to manufacture components in the workshop or by pharmacists to produce medicines in the pharmacy. However, they often lack the many years of process- and material-specific expertise needed to set up the configurations required to achieve the highest possible product quality. This expertise may soon be substituted by machine intelligence. Using the hybrid approach of IWF TU Berlin, equipment manufacturers can adapt the machine capabilities of the equipment and the operator interfaces to enable fully automated calibration and printing through a simple understanding between machines and humans. ◆

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3D METAL PRINTING FOR LARGE-VOLUME COMPONENTS

The challenge: *When printing large-volume metallic components, the process parameters must be controlled adaptively in order to be able to guarantee the required process stability during production and the resulting component quality, even under the influence of unknown disturbance variables. Each of the numerous materials that can be processed, such as mild steel, CrNi steel, tool steel, aluminum or titanium, requires different build-up strategies and process parameters that are also geometry-dependent. For example, buildup strategies for thin-walled structures are usually not transferable to thick-walled structures. Unknown disturbance variables include, for example, varying ambient conditions (humidity, ambient temperature, etc.) and fluctuating wire quality (diameter variance, residues of drawing greases, etc.). These can lead to disproportionately strong slag formation and potential slag inclusions in the component core, but also to bonding defects, porosity, ignition defects or other defect patterns that can only be detected by inline video sequence analysis during production.*

Images: © GEFERTEC GmbH

The approach: *The KIKA module supports workers in making reliable statements about component quality and necessary decisions about process configuration, even under the influence of unknown disturbance variables.*
The vision: *A completely self-learning and autonomous process control based on a plug-and-play approach. There is no longer a need for trained technical staff. The system simply receives the CAD file and the desired material as well as necessary quality criteria to be met as input, and selects the build strategy completely autonomously. It performs slicing as well as path optimization for particularly complex parts of the component, and produces the component under continuous control. Irregularities can be detected, classified and evaluated independently by the KIKA module, which finally leads to the output of a quality protocol of the manufactured component under evaluation of the required quality criteria. The system setup enables continuous improvements in terms of process stability and component quality and independently learns correlations between setting parameters and required output parameters. Thus, with each component production, the system continues to improve itself until ultimately 100 percent defect-free components are produced.*

DRUG PRINTING FOR PERSONALIZED MEDICINE

The challenge: *Using additive manufacturing, it is possible to supply patients with the drugs they require flexibly, locally and individually starting with a batch size of one. However, the challenge lies in patient-specific dosing the various active ingredients with different properties in nanoliters. This requires reproducible and highly precise application of the active ingredients by the technology used. To check the manufacturing process, offline samples are currently taken and analyzed for their active ingredient content in a cost-intensive wet-chemical process. However, wet-chemical analysis for the end customers with small batch sizes is not profitable. To overcome this obstacle to pharmacological production, a 100 percent process control must be ensured.*

The approach: *The KIKA module is to track each drop, determine the physical properties during the drop flight and adaptively control the print head nozzle. The image data will be used to derive the physical properties such as volume, velocity, trajectory, shape, bubble formation, center of gravity, and roundness of the droplets. Furthermore, it is determined whether only a single droplet was ejected or whether so-called satellite formation occurred. In addition, geometry is recorded at the meniscus, which represents the fluid curvature at the nozzle.*
The vision: *Based on the image data, the KIKA module adaptively calibrates the process parameters and regulates them during production. This would optimize the process flow under different conditions and with different active ingredients, while increasing process stability and maintaining complete process control.*

Images: © DiHeSys Digital-Health-Systems GmbH

Putting a Face to Robotics

Interview with Matthias Krinke,
pi4_robotics GmbH

»Workerbot 1« was the name of the first robot developed by the Berlin-based company pi4_robotics in 2010. Today, the 8th generation of Workerbots support industrial companies in handling, assembly and inspection, but the humanoid helpers are also used for building monitoring, concierge services, catering or the care sector. Founder and CEO Matthias Krinke explains in this interview with FUTUR that good technology needs emotions – especially when humans and machines work together.

MATTHIAS KRINKE
CEO, PI4_ROBOTICS GMBH

… studied electrical engineering at the Technical University of Munich and has been founder and CEO of pi4_robotics since 1994. The company, based in Berlin's Wedding district, is a technology leader in the fields of robotics and fully automated image processing. Since 2016, the engineering graduate has also been director of Planet Claire, which conducts research in the field of artificial intelligence, and since 2018 of Robozän Deutschland, the world's first temp agency for humanoid robots. Krinke also acts as vice chairman of the board in the Werner-von-Siemens Centre for Industry and Science e.V..

| futur | Mr. Krinke, your company pi4_robotics is particularly known for its service robots with their friendly smiles. The Workerbot4 Concierge, for example, can receive, brief and inform guests. How important is a humanoid design for robots that are in direct interaction with people?

/ Krinke / Just as a person smiling at you in a friendly way can have a positive impact on your day, the same is true for robots. Think of an ATM, for example: Here, service is usually handled in a simple, straightforward, but also unemotional fashion. Some companies already use check-in machines to welcome guests. But how does a visitor feel when they are received in such a functional and emotionless way? Even if friendliness is only programmed in our robots, it leaves a pleasant feeling. And why should a service only be designed functionally, if it can also be realized in an emotionally appealing way? If this friendliness is linked to a humanoid figure, robots appear more convincing and are better accepted by a human counterpart than a smiley that simply appears on the screen of an ATM.

| futur | In addition to customer service, your Workerbots are also used in industrial production. As a manufacturer, what differences in the interaction between robots and humans do you have to consider for these different applications, for example in terms of design and operability?

/ Krinke / Stationary and mobile robots for assembly and logistics tasks in factories are operated by technically trained personnel. The staff generally interact with them without reservation and set parameters themselves. Design aspects play less of a role here than technical functionalities. In non-industrial applications, on the other hand, a sympathetic design of robots is of greater importance. Here, the focus is on self-explanatory operation that is as language-independent as possible. In our latest product development – a service robot that assists in nursing care – we therefore put a great deal of effort into the design, especially the interface design. In this context, we are also investigating trust-building properties of robots and considering ethical issues and data protection requirements. Implementing such aspects functionally and in terms of design is enormously important, especially in the care sector.

| futur | For an SME, pi4_robotics is exceptionally strong in research. This has been recognized e. g. by the magazine »Capital«, when it gave you an award as one of the most innovative companies in Germany 2021 in the field of mechanical and plant engineering and suppliers. Which of your developments make you particularly proud?

/ Krinke / Each of our developments had and has its challenges for us as a team. It is difficult for me to single out one of them. As a mechanical engineering company, we compete not only throughout Germany but also internationally and can only maintain our market position with the most innovative technology. With this in mind, we at pi4 always try to be at the forefront of technology. However, technology must not be an end in itself, but should always be at the service of the environment and our quality of life. I am particularly proud of the fact that we build very durable machines and robots. Most of the systems we have produced over the past 28 years are still in service today. I am also proud that our technology supports the use of renewable energies and thus helps to ensure the survival of our planet. For example, we develop fully automated inspection systems that are used for quality control of solar cells, fuel cell components and electrolysers. In addition, our diagnostic robots help to detect rare diseases such as ALS at an early stage so that patients can get optimal treatment.

Image:
Concierge robot at »Haus der Zukunft« in Berlin
© pi4_robotics GmbH

| futur | With Robotics4Care you are entering the care sector, which is particularly affected by a shortage of skilled workers. In your opinion, are there limits to the conceivable fields of application for service robots?

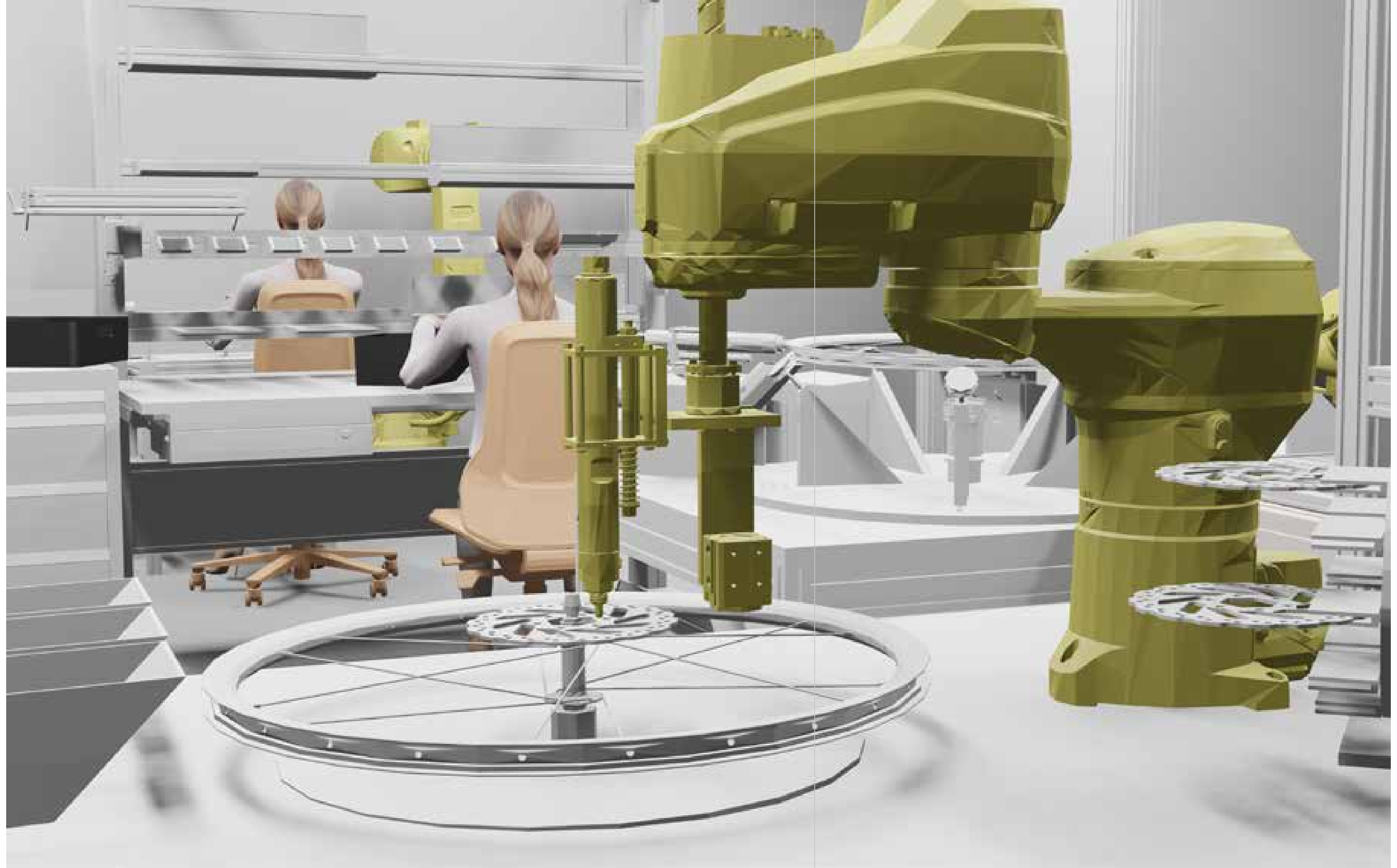
/ Krinke / I am convinced that the emotional and ethical concerns that still exist today will inevitably be overcome by the shortage of skilled workers. Technologically, multimodal sensor concepts, especially integrated force feedback systems, will advance the use of robots in the area of body-related care tasks even more in the future. The biggest obstacle here is still the weight of the human being in relation to a robot's own weight – to balance both carefully and safely in robot-assisted movements, for example, is not trivial.

| futur | Artificial intelligence and machine vision have revolutionized robotics in recent years, too. Which technologies will shape human-machine collaboration in the future?

/ Krinke / VR and XR technologies will permanently change human-robot collaboration. This will require, in particular, lightweight and comfortable glasses or contact lenses as well as special wearables as interfaces, which are already being developed by some tech companies. ◆

Establishing a Circular Economy through Platform-based Systems

A new laboratory allows researchers at PTZ Berlin to experiment with technologies for platform-based production engineering. The aim is to establish a resilient circular economy.



1

The Urban CIRCLAS Lab will allow scientists to develop automation technologies to enable a resilient, decentralized circular economy.

2

Whether it be mobility, accommodation booking or deliveries, the platform economy has disrupted many established sectors in recent years. This principle connects people or businesses offering goods or services directly to the customer through virtual intermediary and collaboration platforms. The success is based on standardized pooling, efficient linking of previously disparate participants and the wide-reaching nature of platform solutions. This type of economic activity has a number of advantages, such as huge resilience and agility. However, no notable spill-over effects into production engineering have been seen so far: Business models in which production orders are flexibly assigned on a platform basis and collaboratively processed have so far been a marginal phenomenon.

What is keeping manufacturing companies from going down this path is mainly the high levels of required validation and the complexity of the services to be provided. High demand of resources and very specific production expertise are also inhibiting factors. Finally, platform-based processing of production orders requires granularization and order-specific ad-hoc reorganization of operating materials, processes, personnel, and expertise. This remains largely unsolved in practice, particularly in the case of production processes that are more complex than producing individual parts based on drawings.

Scientists at the Berlin Production Technology Center (PTZ) are now working on developing the necessary automation technologies to establish a resilient circular economy based on granularly distributed production resources. The aim is to achieve this by linking cloud manufacturing, handling and assembly technologies as well as services over the entire life cycle and end-of-life processes. To this end, the research team intends to design the relevant hardware, software and data architecture, as well as the methodological conventions, in a highly generalizable, standardizable and automatable way. This reduces implementation costs from the very first site and can be duplicated even more cost-effectively for each additional site.

Images:
1, 2
This is what commissioned work in the Urban CIRCLAS Lab could soon look like.
3
Workshop concept for cloud-based urban production

The »Urban Circular Cloud Assembly and Services Lab (Urban CIRCLAS Lab)«, set up for this purpose, is equipped with industrial robots, cobots, metrology, and safety sensors. The concept is rounded off by shop floor and cloud IT with corresponding digitalization and control interfaces. The laboratory supplements the neighboring manufacturing and automation research labs and maker spaces already in place at the PTZ. For industry collaborations, the Urban CIRCLAS Lab offers an innovative environment where automation and handling technology can be quickly configured with the appropriate shop floor IT.

The scientists are using specific case studies to work on research results and industrializable innovations in the realistic environment of the Urban CIRCLAS Lab. An initial specific example of a project is a two-year collaboration with Formhand Automation GmbH to develop a camera-free bin-picking approach using soft robotic grippers.

The researchers are also planning to investigate automated maintenance and end-of-life dismantling processes for electric vehicle battery systems in the new lab. ◆

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