

DRIVEN



by
maxon

60 Years
of Excellence
Est. 1961

**Self-healing
skin: Giving
robots physical
intelligence** p. 30

**Magnetic appeal:
Why Zurich is
attracting so much
robotics talent** p. 35

What drives robots

- 4 Moment
- 6 News
- 11 New products

14 Focus

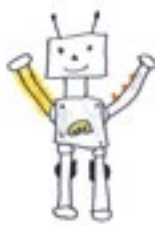
What drives robots



- 14 They're everywhere!
How robots are becoming part of our everyday lives.



- 35 Everyone wants to come to Zurich
We visit Switzerland's robotics hub.



- 20 Visions of the future
How our kids see robots.



- 44 ChatGPT moment
10 key takeaways from the Tech Summit in Davos.



- 40 Expert Insight: Finger drill
Does the perfect hand exist?



- 24 What are the megatrends in robotics?
The Head of Business Development Robotics at maxon reveals it all in our interview.



- 30 Self-healing skin
The next big breakthrough in robotics?



- 48 Moving systems
An overview of robotics solutions from maxon.

- 32 **Robotics glossary**
Are you familiar with these terms?
- 42 **Responsibility**
The challenges presented by autonomous systems.
- 50 **Column**

The heroes of this issue



THE INDUSTRIAL ONE



IDX SERVO MOTORS

→ For mobile robots und autonomous vehicles.
Pages 8, 11, 48

WHEEL DRIVE

→ Ensures that logistics robots find their destination.
Pages 10, 48

THE MOBILE ONE



THE ARTICULATED ONE



HIGH EFFICIENCY JOINT

→ Enables robots to keep moving.
Pages 29, 35, 48

THE PRECISE ONE



HIGH PRECISION JOINT

→ For applications that need to be precise, such as surgical robots.
Page 48



Eugen Elmiger
CEO maxon Group

Technology that sets robotics in motion

Few technology trends are currently attracting as much attention as robotics. However, a robot without movement remains incomplete – and this is precisely where maxon's core competence comes in.

I am delighted to see our products generate such great interest in the robotics industry. A current example is our High Efficiency Joint (HEJ) for robotics. This product is the result of years of research, characterized by perseverance, the ingenuity of our teams, and efficient manufacturing. Today, we have a dedicated HEJ production line, which can be scaled up to handle increasing volumes.

For maxon, robotics is more than just a trend. It has been a central focus for our company for decades. We have been active in humanoid robotics since 1998. When Honda developed its famous humanoid robot ASIMO, it used ECi drives from maxon, which we now produce in Korea.

What really motivates us at maxon is the conviction that we can help shape the progress of humanity with our technology. The potential of robotics in this regard is enormous. This issue of our customer magazine is dedicated to this exciting field and shows how we at maxon are driving the future of robotics.

I hope you find it an interesting read.

LEGAL & CONTACT INFORMATION

Publisher: maxon Group, Brünigstrasse 220, 6072 Sachseln, Switzerland; driven@maxongroup.com / Editor: The maxon newsroom, Sven Gallinelli (Lead Editor), Urs-Ueli Schorno / Realization: Studio Edit GmbH, Zurich: Katharina Rilling (project management), Peter Kruppa (creative & art Direction) / Printing: Druckerei Odermatt AG / Publication frequency: Annually/Languages: German, English, Chinese © 2026 maxon. All rights reserved.

2026-1/Reprint or reproduction only with express written permission.

Photos: maxon



For more exciting news, stories, and technical reports, visit maxongroup.com

FOLLOW US





Everyday moment: ESA astronaut candidate Marco Sieber visits maxon

In January 2026, maxon welcomed a special guest to its headquarters in Sachseln (Switzerland): Marco Sieber, an astronaut candidate for the European Space Agency (ESA) and likely to be the second Swiss person in space, visited maxon for an in-depth discussion about space travel, technology, and the future of exploration. The visit came about thanks to a personal connection – an army buddy of Marco Sieber works at maxon. During his tour, Marco Sieber visited the maxon Medical and maxon SpaceLab teams, where he learned about current projects and technological developments. The direct interaction with engineers led to inspiring discussions for both sides.



Generational change at maxon

maxon's principal shareholder, Dr. Karl-Walter Braun, hands over the chairmanship of the Board of Directors to his daughter, Dr. Bianca Braun

Those who work at maxon often remain loyal to the company for many years. The average length of service in the Swiss maxon companies is just over nine years. The main shareholder of the maxon Group, Dr. Karl-Walter Braun, also contributes to this cut: He officially joined the company in 1977 and will be able to celebrate his 49th year of service in 2026; last year he also celebrated his 80th birthday.

Now the time has come for him to drive forward the generational change in the company. As of June 2026, he will hand over the chairmanship of the Board of Directors to his daughter Dr. Bianca Braun, but will remain a member of the Board of Directors. Dr. Karl-Walter Braun: "A successful generational change cannot be taken for granted. I am very pleased that Bianca is now moving up. She has the right skill set to do so and has known the company from different perspectives for many years."

Bianca Braun helped out in maxon's production departments before and during her studies. She has been a member of the Board of Directors since 2007, and from 2012 she took on operational responsibility as Head of Group Audit and Consulting. Bianca Braun, born in 1978, spent her school years in the Swiss cantons of Obwalden and Zug. She studied Technology Management at the University of St. Gallen and wrote her doctorate on family-run companies. Dr. Bianca Braun: "Family-run companies are a model for success, and maxon is the best example of this – because we think long-term. That was also the motto of my father, who prudently developed the company and, together with the management, led it to its current size. I want to continue on this course and at the same time set new accents."

Robotics

maxon and Pegatron advance mobile robotics together

At Computex Taipei 2026, the Taiwanese technology company Pegatron presented the second generation of its quadruped robotic platform, SIMBA II. For motion control, the company relies on maxon's High Efficiency Joint 90 (HEJ 90).

The compact joint system combines motor, gearbox, and control electronics in an integrated unit. It delivers high torque with precise motion control, meeting the requirements of modern mobile robotic systems. Particularly in quadruped robots, powerful and efficient drive solutions are crucial to enable dynamic movements and reliable operation.

The partnership brings together maxon's many years of experience in precision drive technology with Pegatron's development and manufacturing expertise. Together, the two companies aim to drive the advancement of intelligent mobile robots for industrial, commercial, as well as specialized applications and systems.

For maxon, the project highlights the growing importance of integrated drive systems in robotics. Instead of individual components, complete mechatronic subsystems are increasingly coming into focus.



On launch day, leaders from Pegatron and maxon came together to celebrate the collaboration behind SIMBA II (in the photo from left): Pegatron Co-CEO Gary Cheng, Joe Chan, General Manager of maxon Taiwan, Pegatron Chairman T.H. Tung, maxon Group CEO Eugen Elmiger, and PEGATRON Co-CEO Johnson Teng.



Around the world

The Solar Butterfly has finally arrived

The Swiss solar pioneer Louis Palmer has completed his “Solar Butterfly” project. Supported by maxon, the project aimed to travel around the world in a solar-powered vehicle, raise awareness of climate-related issues, and visit pioneering projects that showcase new solutions for addressing climate challenges. Since 2022, the project has successfully covered more than 100,000 kilometers.

To mark the completion of his project, Louis Palmer also visited maxon's headquarters in Sachseln, Switzerland, where he gave a presentation on the insights gained during his journey. At the heart of his talk was a clear message: the technological solutions for climate protection already exist. “The solutions are there,” Palmer emphasized. At the same time, he raised the question of why we are still so reluctant to

change our behavior. One possible reason, in his view, lies in human nature: “Doing something that restricts us today but only has an impact decades from now requires conscious effort.”

Particularly impressive were the examples from around the world, ranging from large-scale solar power plants in India and long-range solar cars to innovative approaches in agriculture and sustainable materials.

The central concern of Solar Butterfly has always been and continues to be education and outreach. Louis Palmer regularly visits schools with the vehicle and has already reached 70,000 children, with the goal of reaching 100,000 by the end of 2026. And not without reason, according to Louis Palmer, because: “Children can absorb this better than adults.”

Formula Student

AMZ Racing presented race car “Nera”



The Swiss Formula Student team AMZ Racing competed in the 2026 season with the race car Nera. Developed in less than a year, Nera is already the 19th race car from the ETH Zurich and Lucerne University of Applied Sciences and Arts team to hit the track.

As is customary at AMZ Racing, the new vehicle is named after a mountain peak: Roccia Nera is a 4,075-meter-high summit in the Breithorn massif on the border between Switzerland and Italy.

Nera introduces several technical innovations:

- **Carbon monocoque chassis weighing only 17.3 kilograms**
- **Newly developed fully mechanical suspension system with a 30% weight reduction**
- **Four motors further developed jointly with maxon, each delivering 43.5 kW at 28,000 rpm and weighing only 2.46 kg per unit**

maxon continues to support AMZ Racing as one of its main sponsors. The collaboration is especially close in the further development of the drivetrain: maxon engineers work together with the team to optimize the motors. In addition, AMZ members regularly gain hands-on experience through internships in maxon Research & Development.

Closer to customers

Mexico gets its own maxon sales company

Since January 1, 2026, maxon has been operating in Mexico as an independent sales company. Previously, the Mexican market was managed as an agency by maxon's U.S. subsidiary. With this step, maxon is responding to growing demand in Mexico. The goal is to serve customers in Mexico more directly and efficiently in the future. The sales company is headquartered in Guadalajara, and Managing Director Marcial Gähwiler is responsible for local operations.



Success

IDX 70 earns maxon another robotics award

maxon's integrated drive IDX 70 was honored with a RBR50 Robotics Award in Boston (USA). The panel, which selects the 50 most innovative products of the year, recognized the combination of high power density, integrated safety functions, and easy system integration—features that meet the demands of modern robotics applications.

The IDX 70 was developed for mobile robots, autonomous vehicles, and collaborative robots. Thanks to its high torque-to-weight ratio, it enables more compact and lighter robotic systems without compromising performance. Another key feature is the integrated safety functions Safe Torque Off (STO) and Safe Brake Control (SBC). This turns the IDX 70 from a pure drive into a safety-certified subsystem. For customers, this simplifies integration into their machines and supports the safe use of robots in production environments, logistics centers, or applications involving direct human-robot interaction.

Following last year's award for the High Efficiency Joint, a clear trend is emerging: the demand is shifting from high-performance individual components to intelligent, integrated solutions that reduce development effort and accelerate time to market. This is exactly where the IDX 70 comes in, combining drive, control, and safety functions in one compact unit. For maxon, this award is further confirmation that the consistent focus on integrated drive systems meets the needs of the robotics industry.

Space

maxon continues to expand its space activities

With NASA's Artemis lunar program and the rise of New Space, the space industry is currently undergoing transformation—and with it, the requirements for critical systems and components. Starting with Artemis IV, maxon will for the first time become part of applications for crewed space missions.

“Our drive systems have been helping to move rovers on Mars for decades. In the future, they will also be part of applications that contribute decisively to the safety of astronauts,” says Robin Phillips, Head of the maxon SpaceLab.

Entering applications for crewed missions builds on maxon's decades of experience with highly reliable drive systems, including for NASA and European Space Agency (ESA) missions. At the same time, requirements are increasing significantly: applications for crewed missions demand additional redundancies, stricter validation, and uncompromising reliability.

Organizational adjustments

To support this growth and meet future requirements, maxon has implemented various organizational adjustments, including restructuring efforts in engineering and production. At the same time, the infrastructure continues to expand: the Space production area at maxon's headquarters in Switzerland is extending into the cleanroom facility, which the division will share with Medical in the future. These adjustments create the foundation for supporting future space projects even more effectively and for further expanding maxon's space activities over the long term.



maxon portfolio

A new look for the product catalog

The 2026/2027 maxon catalog has been completely redesigned. As part of a targeted portfolio optimization effort, redundancies were minimized and complexity was reduced. The revised product area structure now features clear introductory pages that provide quick access to each portfolio segment. This is complemented by a new “Welcome” section that positions maxon as a company and conveys at a glance what the company stands for.

A special focus is now placed on Market Solutions, which have been given their own dedicated section. Each of maxon's business units (Medical, Aerospace, Industrial Automation, and Mobility) is presented on a two-page spread, with its expertise in the relevant submarkets clearly highlighted.

In addition, the areas of Robotics, Space, and Electronics are presented separately within Market Solutions. This showcases maxon's broad market expertise while enabling targeted browsing and maintaining an overview of its core markets. The “Technology at a Glance” section has also been completely revised.



The new catalog is available here as an e-paper.

Figure

500 kg



Wheel Drive

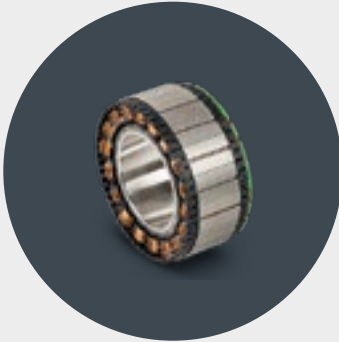
Half a ton on a single drive? No problem. The maxon Wheel Drive moves payloads of up to **500 kg** per drive unit, delivering the ideal combination of power, dynamics, and reliability. With an output of up to **500 W** and a **nominal torque of 40 Nm**, the wheel hub drive provides efficient propulsion. This makes the drive a compact and powerful solution for Autonomous Mobile Robots (AMRs) and other autonomous vehicles.



Learn more

New products

More compact designs, new functions, integrated safety features, and complete systems for robotics and industrial applications: Here is an overview of five recent additions to the maxon product portfolio.



EC frameless DT 50 M

For integrated drive systems

The EC frameless DT 50 M was developed for applications where the motor can be integrated directly into a customer's system. Thanks to its separate rotor and stator design, the drive can be easily incorporated into existing mechanical structures. The brushless motor combines high efficiency with dynamic torque and a compact design. This makes it particularly suitable for robotics, industrial, and medical applications where installation space and weight are critical factors.

GSW 20

Compact strain wave gearhead for precise motion

The GSW strain wave gearhead series has been continuously expanded since its introduction. These gearheads transmit high torque with precision and efficiency and can be combined with a wide range of maxon drives. With the GSW 20, maxon adds a compact option for applications with limited installation space. Combined with an ECX PRIME motor, it forms a space-saving drive unit for robotics and automation applications where precision and compact integration are essential.



IDX 70 Safe Control

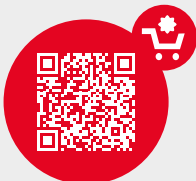
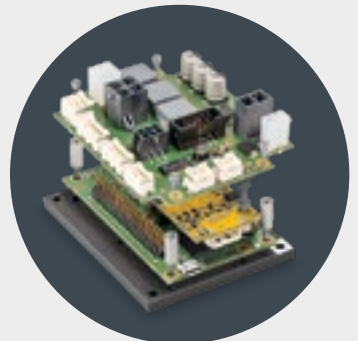
Industrial drive with integrated safety

The IDX series was developed as a plug-and-play drive solution for industrial applications and autonomous vehicles. With the IDX 70 Safe Control, maxon expands the range with a version featuring integrated functional safety up to SIL3 / Performance Level e, Category 3. The drive combines motor, gearhead, encoder and controller in a single compact unit. This reduces integration effort for machine builders and system manufacturers, particularly in industrial automation and intralogistics applications.

EPOS4 Compact STO and MiniMACS6

Safety and connectivity

Functional safety is becoming increasingly important in motion control systems. maxon is therefore continuing to expand its electronics portfolio in this direction. One example is the EPOS4 Compact 60/20 STO featuring Safe Torque Off functionality. The portfolio is further complemented by compact controllers such as the ESCON2 Nano 24/2 and ESCON2 Micro 60/5. Also newly available is the freely programmable MiniMACS6 multi-axis controller with a Profinet interface for networked automation applications.



maxon online shop:
Here you will find more than 6,000 products, selection
aids, combination tools, and comprehensive product
information: shop.maxongroup.com



The motor as a sensor: How maxon MIND is rethinking condition monitoring

Predictive maintenance begins in the drive system: With maxon MIND (motion insights and diagnostics), maxon has developed a solution that turns the motor into an intelligent sensor. Through machine learning, physical expertise, and an open architecture, maxon MIND enables precise condition monitoring – transparent, traceable, and ready for industrial use.

Text: Claude Jaquemet

In industrial drive technology, the motor has long been more than just an actuator. It provides valuable information about the condition of the entire system – provided you know how to interpret the data correctly. This is exactly where maxon's new solution, maxon MIND (motion insights and diagnostics), comes in. The system uses motor signals to draw conclusions about the condition of the drive system and its environment. The development team at maxon sums up this approach as follows: "This turns the motor into the best sensor in the machine."

maxon MIND was developed to take condition monitoring and predictive maintenance to a new level. The solution analyzes data read from the controller during machine operation and detects patterns that indicate wear or malfunctions. It's not just about monitoring the motor itself, but the entire drive system and the related mechanics. This allows deviations to be detected early.

The possible applications are diverse. maxon MIND is particularly suitable for scenarios where unexpected

failures must be detected early – be it to increasing personnel safety or minimizing downtime.

It also identifies issues that remain hidden in traditional tests. In production lines with multiple machines in sequence, maxon

MIND can help identify even the smallest deviations before they affect downstream processes. In addition, the system adds value in service operations for applications where the actual condition of the equipment is critical for maintenance planning.

Explainable, optimized AI: minimal data, high traceability

Technologically, maxon MIND is based on explainable artificial intelligence. This ensures that all diagnoses and predictions are traceable – a key requirement for safety-critical and highly regulated applications. The machine learning model developed by maxon also requires minimal data and can run on simple hardware. The advantage: minimally invasive integration into the application and low time investment for model training. Furthermore, the model does not require GPU infrastructure,



New products

which is a cost advantage for new developments. Retrofits in existing applications are also possible.

Data processing follows a clearly structured workflow. First, raw data is collected during machine operation. It is then preprocessed before entering the machine learning model. The model checks the data and analyzes any deviation from a healthy operating state. The result is then available through an Application Programming Interface (API). Glassbox instead of black box: every processing step is traceable.

The system learns from real-world applications

A key feature of maxon MIND is the integration of domain-specific expertise into the model. The physical relationships of a mechatronic system flow directly into the modeling process. This achieves high prediction quality with minimal data requirements. The system also learns from real-world applications: during machine commissioning, an initial state is recorded that describes the motor in the context of its environment. During operation, new data is regularly fed in and compared with the model. Depending on the application, this happens hourly, daily, or simply as needed.

Data quality plays a central role. To achieve valid results, the recorded signals must sufficiently represent the machine's operating state. That's why maxon works closely with customers to define suitable measurement cycles. These may include standardized motion sequences that reflect typical load situations. This creates a robust model tailored to the customer's application.

An open platform

Data handling also plays an important role in maxon MIND. By default, data processing takes place in the cloud. Customers can view and download their data. No personal information is required, and all data can be anonymized by the customer (exceptions: the article and serial numbers of the maxon components).

The platform is designed to be open. Customers can access their data and integrate it into their system environment through an API. The solution is minimally invasive: existing motors, electronics, and controllers remain unchanged. The only requirement is installing a software package on the master controller that transmits data via, for example, the Message Queuing Telemetry Transport protocol (MQTT). If the machine is already connected to the internet and the controller can acquire data, the system can be operational within a few days. All necessary specifications have already been defined.

Requirements and compatibility

One advantage of maxon MIND lies in its high compatibility with existing systems. The solution is designed to integrate seamlessly into various drive configurations –

regardless of industry or application. Existing hardware such as motors, controllers, and electronics does not need to be replaced. maxon MIND can also be used in principle across the entire maxon drive portfolio, provided that the corresponding motor is equipped with a controller.

Technical focus, industrial robustness, open architecture

In the market, maxon MIND positions itself as a highly specialized solution for demanding applications. maxon pursues a focused approach that deeply analyzes the physical properties of the drive system. This combination of technical focus, industrial robustness, and open architecture makes maxon MIND a solution that not only collects data but delivers real insights.

With maxon MIND, maxon brings a well-thought-out, technically sound solution to the market that turns the motor into an intelligent sensor. The combination of machine learning, physical expertise, and open system architecture makes the system a future-proof tool for industrial applications. The motor thus becomes not only a drive but a central element of condition monitoring – and therefore, the key to greater efficiency, safety, and availability in Industry 4.0. [REDACTED]



About Claude Jaquetmet

Claude Jaquetmet is Business Development Manager Digital Business at maxon. He has worked for the maxon Group for almost a decade. In the field of drive technology, seamless integration into the digital world is increasingly becoming a decisive success factor. Together with his team, Claude Jaquetmet develops customer solutions in this area.

A new era

We find them in hospitals, warehouses, labs, and care facilities, they travel into space for us – and their numbers are growing every year. Robots are everywhere these days. We've compiled a small selection of the many diverse, specialized, and surprising robotics applications around right now.

Text: Sven Gallinelli

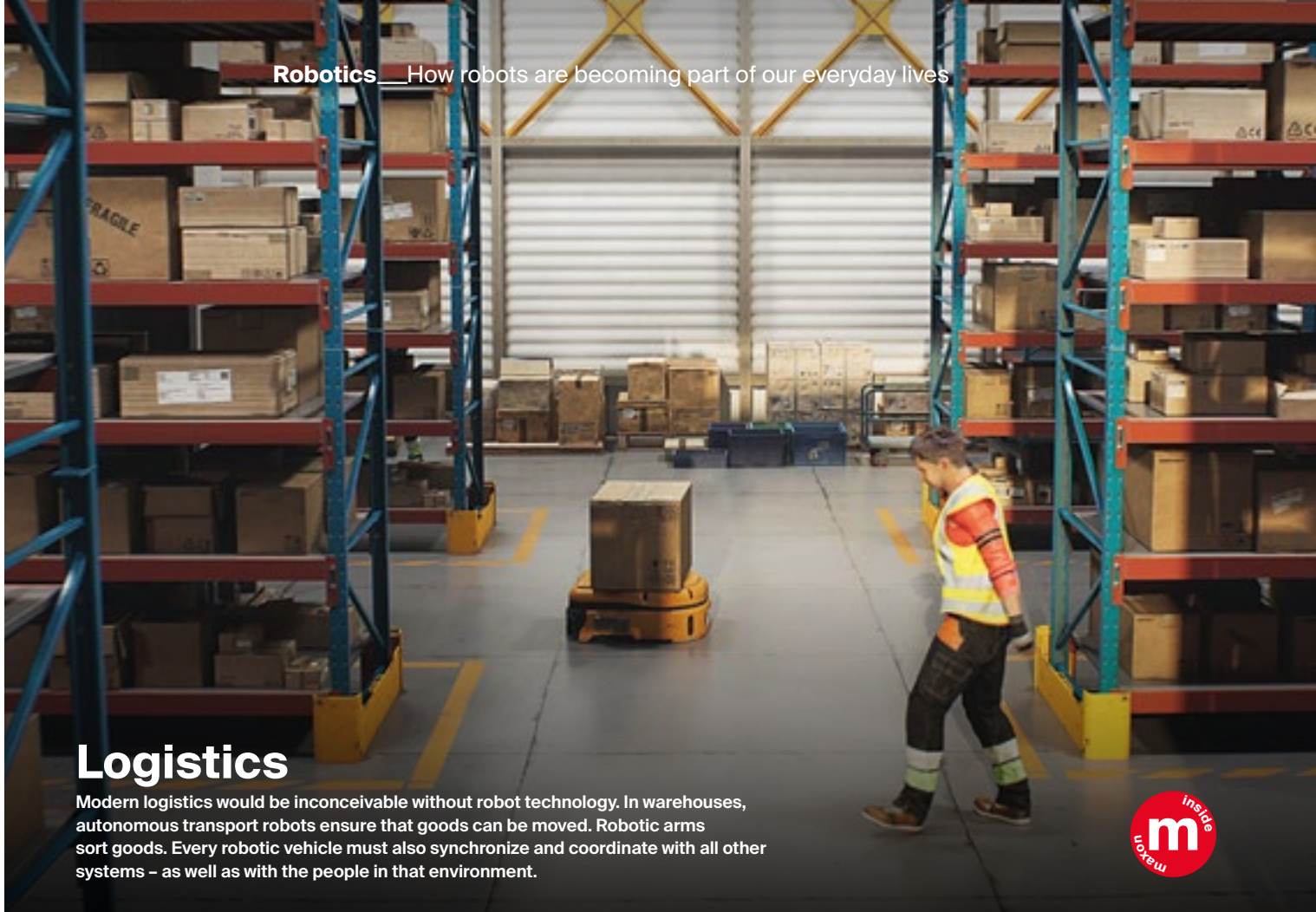


Space

Robots, among them the NASA rover Perseverance, are used to explore distant planets like Mars. Systems such as robotic arms assist astronauts on space stations. In satellite systems, they support manipulation. Quadruped robots could even play a role in a Moon landing mission.

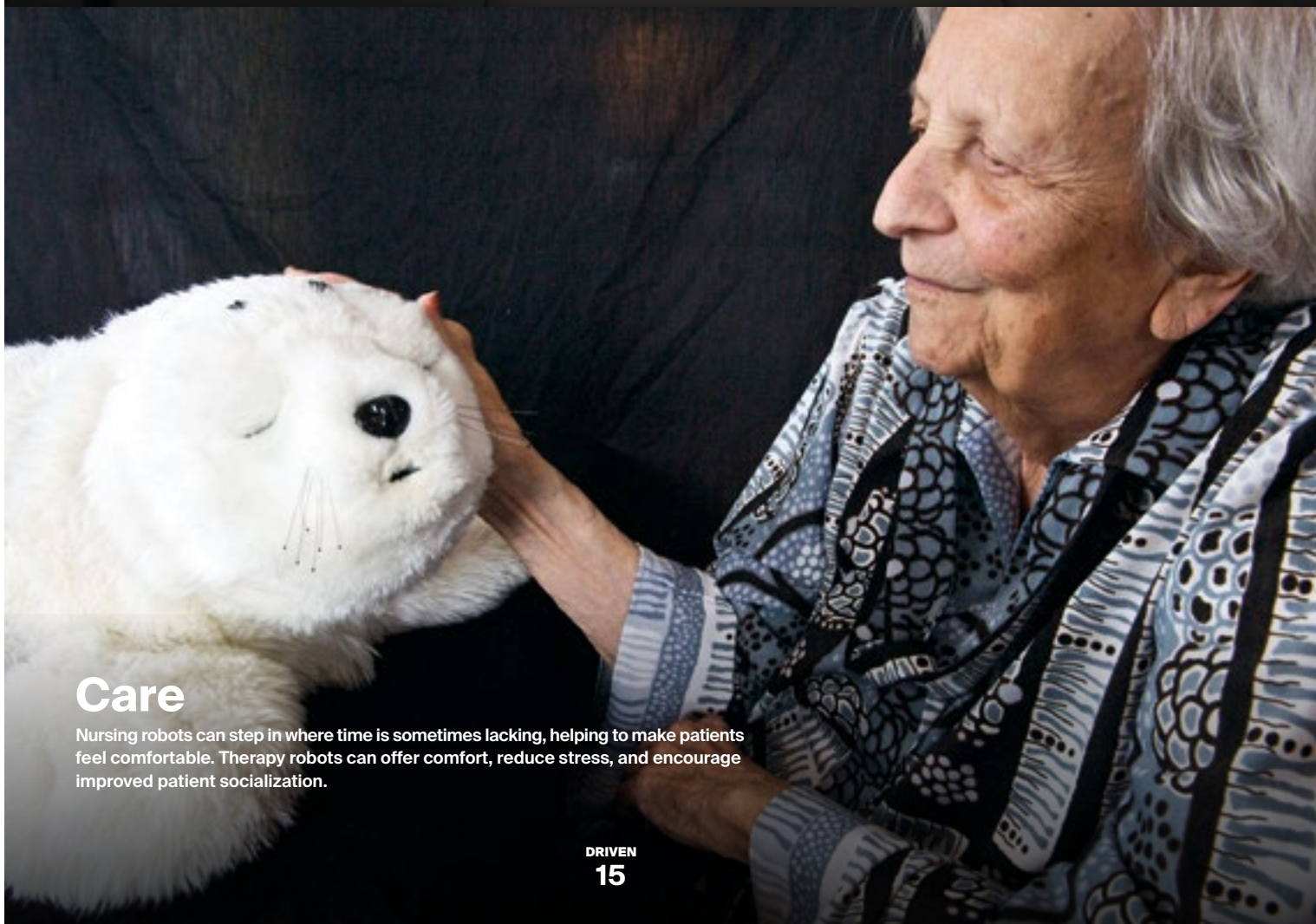
maxon inside!





Logistics

Modern logistics would be inconceivable without robot technology. In warehouses, autonomous transport robots ensure that goods can be moved. Robotic arms sort goods. Every robotic vehicle must also synchronize and coordinate with all other systems – as well as with the people in that environment.



Care

Nursing robots can step in where time is sometimes lacking, helping to make patients feel comfortable. Therapy robots can offer comfort, reduce stress, and encourage improved patient socialization.

Industry

Industrial robots have been used for a long time, especially for repeatedly and precisely executing workflows. The next generation of industrial robots can do even more. Thanks to physical AI, they are becoming intelligent, can make their own assessments thanks to sophisticated sensors, and react autonomously.



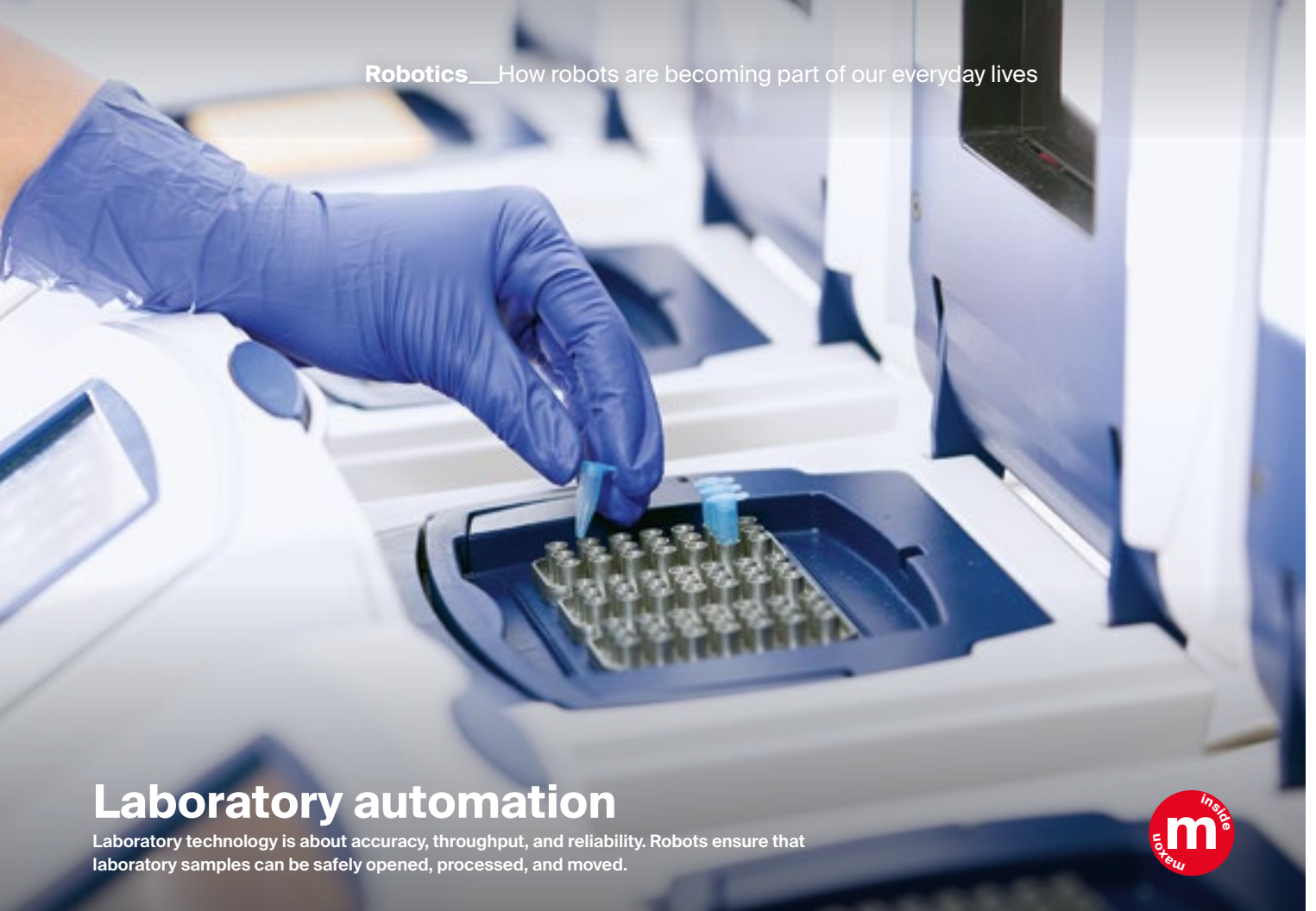
Households

Unpopular household chores are now being taken over by robots. The robot vacuum cleaner is one of the best known, but there are also window cleaning robots, robot mops, and security robots. What robots currently can't do (and won't be able to do in the near future) is empty the dishwasher – because they lack the necessary tactile skills.



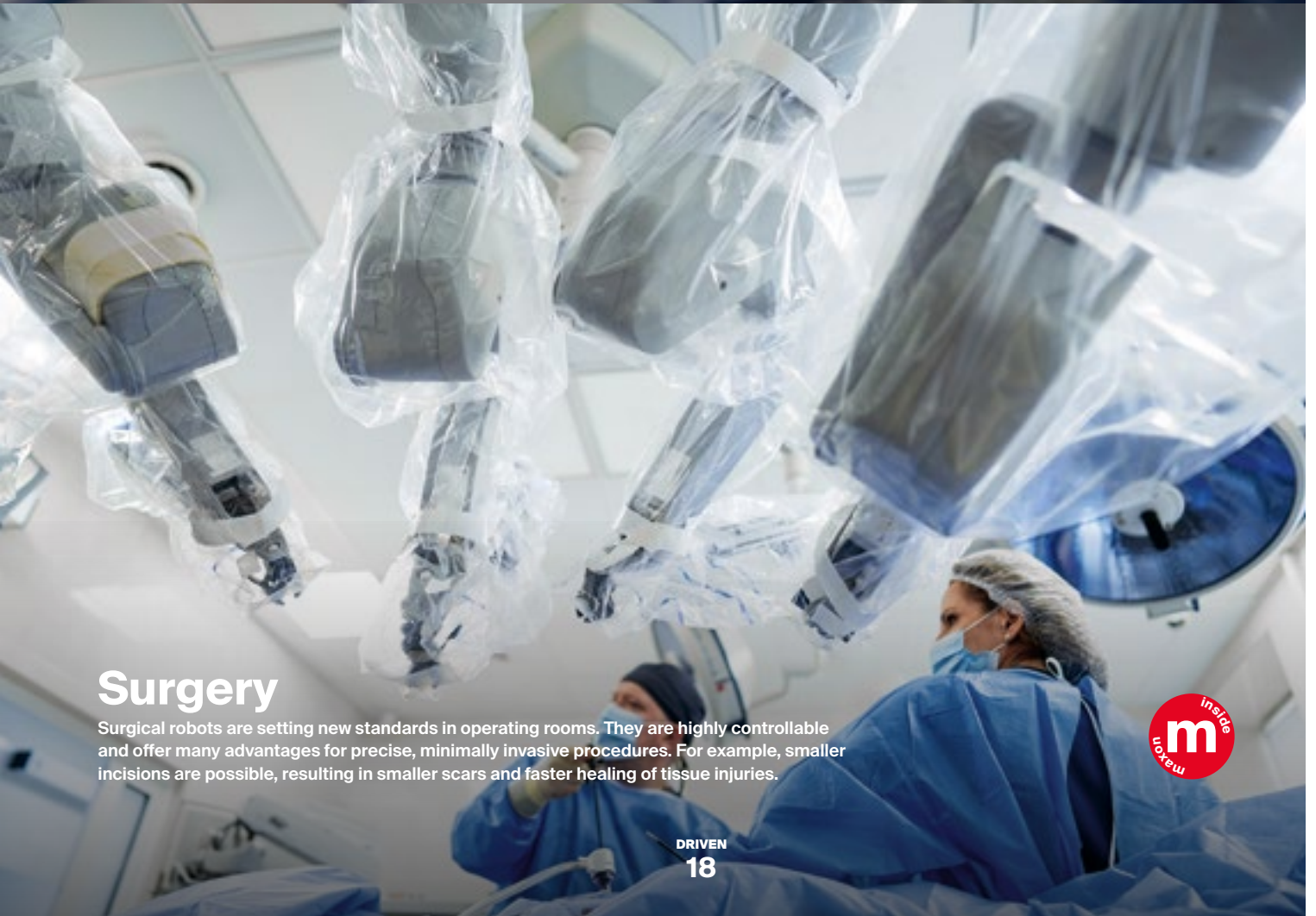
Humanoid robots

Until now, humanoid robots have often been considered a gadget. With artificial intelligence, however, they can become thinking systems and move freely even in unstructured environments. This allows them to autonomously take on more complex tasks in industry – or to work hand in hand with humans.



Laboratory automation

Laboratory technology is about accuracy, throughput, and reliability. Robots ensure that laboratory samples can be safely opened, processed, and moved.



Surgery

Surgical robots are setting new standards in operating rooms. They are highly controllable and offer many advantages for precise, minimally invasive procedures. For example, smaller incisions are possible, resulting in smaller scars and faster healing of tissue injuries.



Quadruped robots

Quadruped robots are ideally suited for applications such as inspections. They can autonomously inspect industrial facilities or perform tasks in inhospitable or dangerous environments. Quadruped robots are also suitable for use as logistics robots. AI integration is now making these robots smart.



Mobility

Cars today have modern assistance systems, such as lane departure warning systems. This turns them into robots that can move in semi-structured environments.

How our kids see robots

Alongside superheroes, dolls, and cars, robots are considered classic toys. Almost every child immediately has an image in their mind when they think of robots. A study has shown that the way children imagine robots can provide clues about what they expect robots to be capable of in the future and how they feel about them.

Text: Sven Gallinelli/Katharina Rilling

A team from the Department of Education and Learning at the University of Applied Sciences and Arts of Southern Switzerland presented around 100 schoolkids with the following challenge: “What picture comes to mind when you think of a robot? Draw it!” The drawings could be roughly divided into three categories. Some robots were angular and humanoid. Others were also humanoid but featured rounder, smoother shapes. A third category included robots without human features, such as robotic arms, vacuum cleaners, or rovers.

Interestingly, children whose drawings were more fictional in nature were more likely to believe that robots would one day take over their parents’ jobs, while children with more realistic portrayals of robots were more skeptical. These findings should be interpreted with caution, but they do offer insights into how educational robots and learning activities can be designed so that children not only want to learn with robots, but also better understand what robots are and what they can do. ■

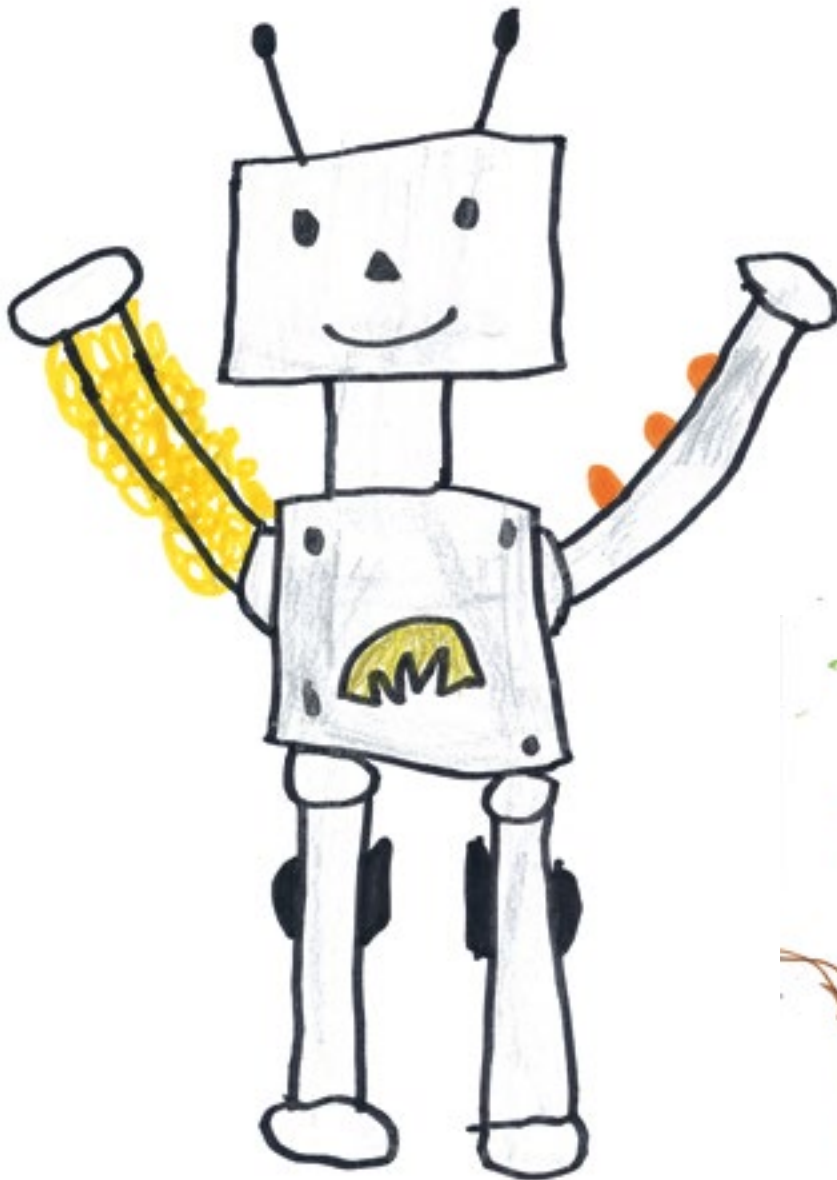


Tiara, age 4½



About the study

We asked the kids of maxon employees to draw a picture of a robot. Here are the results!



Eyla, age 6

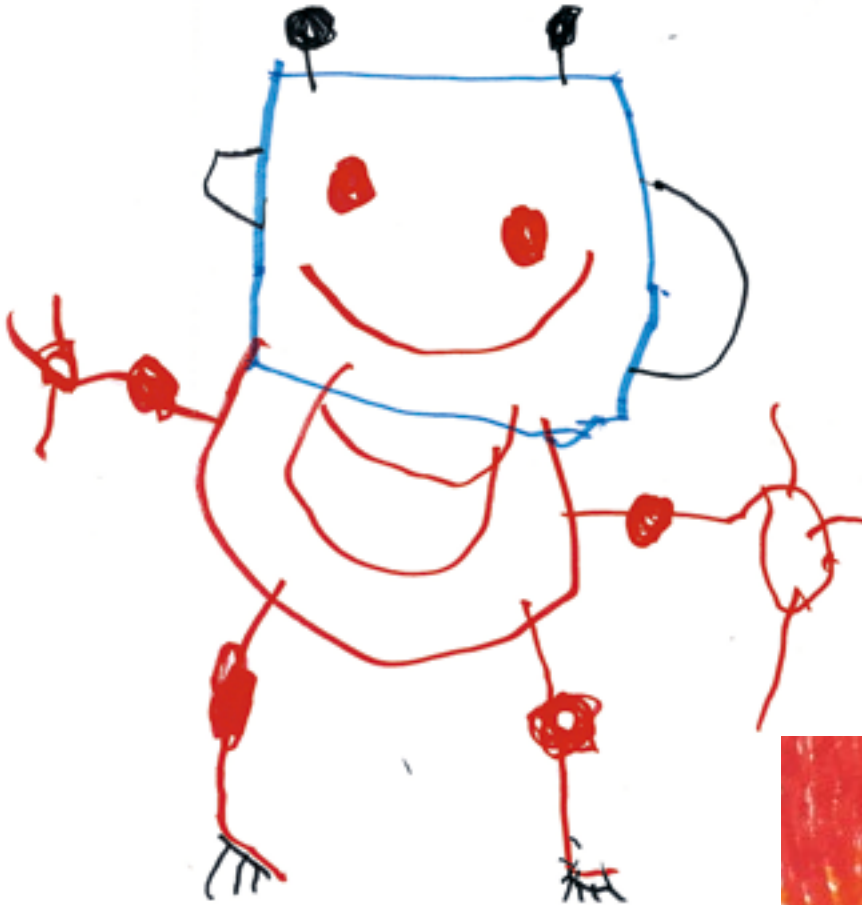


Bryan, age 5



Iman, age 2½





Marlo, age 4½

Pioneering work for families

maxon Group's headquarters has had its own daycare center since 1972. What is seen as commonplace today was a true pioneering achievement at a time when very few companies invested in their own daycare centers. maxon set an early example for family friendliness and for a better work-life balance.

This commitment continues to this day: 24 children attend the daycare center and are lovingly cared for by Regula Bühler and her team of ten staff members, including three apprentices. Regula Bühler knows the daycare center better than just about anyone else. Having started there as an intern 35 years ago, she now manages the facility.



Aren, age 3½



Enor, age 4



Afan, age 5



Hana, age 4

“A bag of chips poses a difficult problem for a robot”

At ANYbotics, he helped develop one of the world's most advanced walking robots. Today, Mario Maurer makes it possible for robots to move in the first place. At maxon, he heads the Business Development Robotics. In this interview he explains why the humanoid hype has more substance than its reputation suggests, the direction in which robotics is developing, and where the limits of the technology currently lie.

Interview: Sven Gallinelli **Photo:** Lucas Ziegler



What's the megatrend in robotics?

Building robotics hardware has become much easier in the last ten years, partly due to the emergence of a huge ecosystem of suppliers, battery providers, motors, computers, and sensors. This development was driven by the smartphone boom, which made computing power, as well as cameras and 3D sensors, available in compact form factors. These are all building blocks needed to construct a good, modern robot capable of autonomous action.

And then artificial intelligence came along...

That's the second big trend. Even before the chatbot era, early research on this topic was already being conducted at ETH Zurich. At that time, the focus was on how machine learning could be used to control robots. Machine learning was very important, and the increase in available computing power was a key driver. Today, modern artificial intelligence can quickly process and interpret large amounts of data – video signals, motion signals, sensor data – everything that a modern robot needs to quickly evaluate in order to function.

Why is it so important?

The more data is processed, and the faster it is processed, the sooner a robot can react autonomously because it understands the context of its actions: where it is supposed to go, what tasks it is supposed to perform, which parts it is supposed to assemble. While the topic still requires a great deal of research, this major trend has sparked a considerable amount of excitement in robotics.

What exactly is the source of this excitement?

With the advent of AI, it's becoming clear that robotics will take another decisive leap forward in the next ten to twenty years. Robots will increasingly influence our daily lives, and we will encounter them more frequently – because they will be able to operate safely and autonomously around





Inside maxon's manufacturing facility: This is where the robotic drives are produced.

humans. Thanks to good, robust hardware and computing power. And to software systems that can handle this data and complexity.

In the fictional world, robots can do everything: replace humans, move effortlessly, and master even complex tasks. In reality, the picture is more mixed. Are we getting closer to Hollywood's version of a robot?

It will take a few more years. Initially, robots will take on more and more tasks in controlled environments for industrial applications, in defined settings for the time being. For example, a robot currently carries a box from point A to point B. That's simple. But we're already seeing ways this can be expanded into more versatile applications.

The running joke in robotics is that robots can't handle simple tasks - like emptying the dishwasher.

Yes, it may sound funny. But when robots are capable of emptying our dishwashers, making our beds, or vacuuming our homes completely autonomously, then we will have reached the end of the technological journey. Sure, robots can already perform some of these tasks, but these are mostly just proofs of concept, and so far, this only works to a limited extent. At least the proof that it's fundamentally possible has been provided. It will take a few more years before such tasks can be performed reliably, safely, and efficiently.

Robotics systems used to be relatively simple: a sequence of actions was programmed and then repeated countless times. Today, these systems are more complex. What exactly is this complexity?

The difference between modern robots and traditional industrial robots lies in the interplay of sensors, interfaces, and points of contact that a modern robot has with the real world. A modern robot relies on sophisticated sensors to dynamically perceive its environment. This environment can change at any time, meaning the robot must constantly reassess, process, and react appropriately. Modern robotics

Photo: Jeremias Wieland, maxon

is therefore far more multimodal than its predecessors.

Let's take logistics as an example...

When we shop online, the goods are delivered to us from a warehouse. These warehouses have become highly complex facilities where robots perform a wide variety of tasks. For example, there are autonomous transport vehicles that move boxes. Often, they do this along a defined path in a controlled environment. However, the trend is moving toward these robots also operating in uncontrolled environments – in other words, where people are present. But the limitations of robotics are also becoming apparent in logistics. Let's say a robot has to retrieve a bag of potatoe chips from a box – it will be a challenge for it to do so without damaging the bag.

Are there applications where multimodality already works well?

Yes. One example that we all know is the car. Modern cars consist of a multitude of systems: an engine, a camera system for the lane departure warning system, radar sensors for the adaptive cruise control, and several computers that manage the car and react to these sensors. The next step is self-driving cars that need to be able to make reliable decisions independently.

What exactly is a robot? Isn't just about any technical system a robot?

Interesting question! Is a plane a robot? Is a dishwasher a robot? Actually, an industrial robot isn't really a robot either, but a controlled machine, right? Is a robot a machine that can react to an unstructured environment? Maybe. But a plane's autopilot can do that too. Engineers say that when you see a robot, you'll know whether it's a robot or not (laughs). I'd define it like this: If an embodied system acts autonomously and can physically interact with its envi-

ronment without needing to be controlled, then it can be called a robot.

According to that definition, would a car equipped with modern driver assistance systems be a robot?

The car is probably a borderline case. A lane departure warning system is essentially a robot. It interprets signals from its environment and reacts to them. On the other hand, it needs the lines on the road to function. Therefore, it only reacts to a semi-structured environment. If a child runs onto the road and the vehicle brakes, that again has robotic characteristics. A self-driving car would thus clearly be a robot. What the car seems to lack is physical interaction with its environment. But one thing we can all agree on is that a dishwasher is definitely not a robot (laughs).

It took quite some time for cars to reach their current state of technology. What's the timeframe for robotics?

Humanity had roughly 100 years to develop the car to its current level. We won't need nearly as long for robotics. Assuming that modern robotics began in the 1990s, it will likely take a maximum of 40 years for the technology to mature. A robot is much more compact than a car, but it has a similar level of complexity and uses very similar systems. However, the limited space makes integrating components more complex. This is the big challenge facing engineers and makes robotics primarily a systems engineering task.

Could you say that, mechanically speaking, robots have been invented, but the challenge now lies in combining the mechanics with all the digital systems and software?

Ideed. The mechanics that drive robots are systems that are very well understood and controlled. Electric motors, gearheads, mechanical engineering, and electronics have been around for a long time. Major changes in mechanics will only occur if there are advances in materials science, which might then allow for even more efficient utilization of flux density or fill factors in electric motors, thus increasing performance. However, the system archi-

“When you see a robot, you'll know whether it's a robot or not.”

tecture and the interaction between hardware and software are far more important. There's a saying: “Software eats hardware.” In robotics, this only applies if you have a truly thorough understanding of the hardware and its behavior. Then, certain complexities can be shifted to the software without negative consequences.

When you talk to people about robotics, they immediately think of humanoids. These robots are celebrated for even the smallest successes, for example, when they manage to climb a flight of stairs. At the same time, however, they are also the least commercialized type of robot – because there seems to be no practical application for them. Are humanoids more hype than substance?

The fascination with humanoids stems from popular culture. Movies exploring this theme began to appear as early as the 1940s. The phenomenon continued its rise to prominence with movies like Star Wars and Terminator, in which humanoids moved very naturally. In real life, as I've mentioned, it's more complex. The technology hasn't yet been made ready for mass adoption. However, the hype surrounding humanoids isn't inherently negative, as it brings attention to the topic. Robotics companies receive funding for their developments, which fosters expertise and enables the construction, scaling, and mass production of humanoids.

Humanoid robots also benefit from developments in artificial intelligence. In this context we talk about physical AI, meaning AI that works in conjunction with mechanical systems. How far has the development of physical AI progressed?

This field is still in its infancy and requires a lot more research. For a passive system that performs a task but doesn't yet need to interact with its environment, physical AI is currently pretty capable. In

“When robots are capable of emptying our dishwashers, then we will have reached the end of the technological journey.”



industrial inspection, for example, it already works reasonably well. Robots can move, react passively to their environment, and detect if there are any problems. Wherever robots and humans work together, safety must be guaranteed. However, robustness, reliability, and safety remain major concerns, especially for systems that perform manipulations, such as opening doors, transporting objects, bringing a tray to the table, and yes, even unloading the dishwasher. Physical AI can make a crucial contribution to progress in these areas.

AI with language models has a tendency to hallucinate. What about physical AI? Does it also tend to completely misjudge situations?

Yes, this will happen and will likely be a functional disadvantage of this technology. While it is very capable, it sometimes acts unpredictably. Depending on the application, this can have far-reaching consequences. In the case of language models, hallucination has been significantly reduced in recent years. However, much more research will be needed with physical AI to manage these risks.

Another problem is regulation. There are currently no standards specifying what conditions or norms physical AI must comply with, or how a robot should behave in an unstructured environment.

Regulation is clearly lagging behind. The EU is attempting to address the issue early with its AI Act. On the other hand, there is also an interest in not stifling development too soon. Those who master robotics technology early have an advantage over other countries. However, regulation will be necessary to scale these technologies, if only to ensure their safety. ■



THE HIGH EFFICIENCY JOINT – A TECHNICAL HIGHLIGHT

Mario, maxon makes it possible for robots to move. Together with the teams at maxon, you develop our actuator solutions for robotics. How important are actuators for a robotics system?

The fact that a robot moves is its central element. Without movement, it cannot create value. Movement requires torque and force. This force is generated by electromagnetic actuators, either rotary or linear. Our core competence lies in the

Photo: maxon

targeted conversion of electromagnetic force and torque into different forms of movement, thereby providing the appropriate movement at the right place.

One of our product highlights for robotics is the High Efficiency Joint (HEJ). What is the concept behind this integrated actuator?

Our High Efficiency Joints are a platform of highly integrated, modern drive systems for robotics. The level of integration is crucial. These are motor, gearhead, and controller combinations that are perfectly matched, and where numerous features are provided by the firmware running directly on the actuator. This allows our customers to easily integrate the system into their robotics applications. Because many features are provided by the software, the mechanical complexity is relatively low.

Does this mean that the software takes over tasks that were previously the responsibility of the mechanics?

Exactly. However, the reduced complexity of the mechanics doesn't mean the joint is a simple product. Reducing hardware complexity requires extensive engineering and testing. It's essential to ensure that the right performance is combined with the features that roboticists actually demand. With our High Efficiency Joints, we've struck a good balance. Not just technologically. The system is highly scalable and also cost-effective for customers.

The High Efficiency Joint is based on a joint development with the Zurich-based robotics start-up ANYbotics, which manufactures quadruped robots. You yourself used to work at ANYbotics. The development of the joint took several years. Why did it take so long?

Let's take a look at the history of drives in robotics: In the past, a drive was needed that could measure the output torque relatively accurately and precisely. This was achieved with a series elastic actuator. It had a spring in the output, and this spring allowed for a relatively accurate measurement of the output torque. This was necessary at the time because robot controllers

were model-based. Researchers at ETH Zurich experimented extensively with this technology and even built ANYmal robots that operated with such actuators. Unfortunately, these were not reliable. The controllers had to be set very precisely, which made them somewhat inflexible.

In other words, it was a purely mechanical system and too rigid for everyday use.

Exactly. And then came the paradigm shift around 2019, when suddenly machine learning became possible. This led to the controller on the robot being able to operate in a much more robust way. This is when the first neural networks came into use. They were relatively simple, still a long way from artificial intelligence. But the networks could be trained in simulations; so, overnight, it was suddenly possible to deal with much more complex environments. The actuators, in turn, no longer needed to function with mechanical precision, which meant that the mechanics could be designed more simply. Springs were no longer needed, a simpler motor-gearhead combination was sufficient. While this could adjust the torque with only reasonable precision, it was adequate for the application. This is called a Quasi Direct Drive.

So you had a new starting point for actuator technology in robots. What were the consequences of this?

We could no longer use the actuators we had developed previously for the ANYmal robots. We therefore had to start from scratch and develop a system tailored to the new technological situation. This led to the development of today's High Efficiency Joints, in which mechanics and software are integrated and perfectly coordinated.

So, for many robotics applications, the mechanical part of the drive no longer needs to be so precise, because this can be compensated for by software?

Yes, for a robot operating in unstructured environments where the accuracy of its 3D sensors is somewhere in the centimeter to millimeter range, a highly precise drive isn't necessary. However, we're only

“The system is highly scalable and also cost-effective for customers.”

talking about the mechanical movements here. Of course, the drive itself needs to be precise: it must be able to accurately interpret signals. But it doesn't need to be able to set its output speed, torque, or position down to a hundredth of a millimeter, because the robot can compensate for and correct these inaccuracies with its software. This is sufficient for certain applications. It's important to note that other applications, such as surgical robots, require greater accuracy. Other maxon solutions are used here.

If you had carte blanche, which actuator solution for robotics would you develop in the future?

If I were to bring something new to market, it would have to be something that utilizes a fundamentally different physics than what we've seen so far. Perhaps something that no longer primarily uses electromagnetic actuation. Electrostatic actuators would be a good example. Research in this area is still in its infancy. But you could also start with materials science (see page 30): Are there exciting materials that can change physics? There's a lot of potential for innovation there, even for a company like maxon. However, it will take years of research before any progress is made in this area.

How to give robots body self-awareness

Artificial intelligence is making robots smarter. But machines fail precisely at what comes easily to humans – grasping, sensing, adapting.

Professor Hedan Bai seeks the solution to this problem not in algorithms, but in the body itself: in materials inspired by biology that are intended to give robots physical intelligence.

Recorded by: Katharina Rilling

“What drives me? My dream: to develop robots that not only act as intelligently as humans, but whose bodies also possess some of the adaptability that biological systems have developed over millions of years of evolution. To achieve this, we must think of robots differently: not just as machines with algorithms, but as physical systems – complete with materials, sensors, and actuators that can perceive, react, learn, and change.

No brain without a body

Until now, robots have primarily been used in defined environments and for clearly defined tasks. Newer models, however, are intended to support us in uncontrolled situations as well: at home, in hospitals, or in factories, where robots are increasingly taking on more complex tasks. But can robotic technologies, originally developed for highly precise and repetitive processes, cope with this new kind of challenge – with situations characterized by uncertainty, changing conditions, and multitasking? We are demanding nothing less of them than to act like humans.

For this reason, it makes sense to use ourselves as a model in research. A key approach in robotics deals with *embodied intelligence*. This involves directly connecting artificial intelligence, a kind of brain, to a robot's body so that it can perceive its environment, make decisions, and act intelligently.

However, when we consider the human body, we see how fundamentally different it is from current robot bodies. In robotics, we speak of actuators – components that generate movement. In humans, this role is fulfilled by muscles. We

have hundreds of them, working together in a finely tuned manner. As soon as it comes to which “muscles” a machine uses or what information it perceives and processes from its environment, the AI-centric approach reaches its limits. Current systems are still far from the agility, versatility, and naturalness with which humans act.

This reminds me of Moravec's paradox. It states that the very things humans do effortlessly – walking, grasping, balancing, seeing, navigating complex environments – are extraordinarily difficult for robots. Conversely, tasks that seem challenging to us, such as arithmetic or playing chess, can be formalized relatively easily for machines. The reason lies in our evolutionary history: what seems natural to us today is the result of millions of years of adaptation. Humans are not just intelligence, not just a brain. Nature has produced bodies that constantly perceive, react, compensate, and learn. This apparent naturalness is one of the greatest challenges for robotics.

Our research seeks to close this gap and forge a new path. We ask: what materials, structures, and actuators are needed for robots to one day become as powerful, adaptable, and versatile as biological bodies? Our goal, therefore, is to develop physical intelligence in the materials used in robots.

Adapt, train

A key aspect here is adaptability – the ability to adjust to changing conditions. When we are injured, our bodies often heal themselves. However, if the surface of a robot is damaged, it is simply broken. When we repeated-

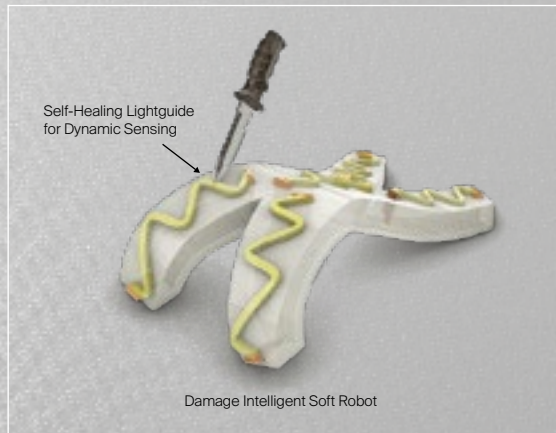
ly perform certain tasks, such as working with a hammer or playing tennis, we learn. Through practice, we become better, more precise, and more efficient. Our muscles continue to develop. This doesn't yet happen with robots. The central question, therefore, is: how can this continued development and training be transferred to the materials used in robots? Much as I love AI, I also see a great deal of potential in this area.

We're examining materials that are fundamentally different from what's currently used in many robots. My recent work with soft, intelligent materials is one example. Self-healing properties can be incorporated into such materials, for instance, in robotic sensors that can repair themselves after damage. The advantage is that the material can be repeatedly cut, and each time it heals itself. This not only creates a more robust system, but the robot can also recognize when it has been damaged, react accordingly, and simultaneously restore its function – with no external intervention.

I call this damage intelligence: a form of intelligence that lies not only in algorithms, but also in the way the material itself deals with damage, healing, and restoration.

Another focus of our research is using light as a stimulus to trigger robotic functions, such as movement, actuation, or sensing. The inspiration comes from communication technology. Information used to be transmitted via copper cables, but today a large part of global communication runs over fiber optics. The reason is simple: a single optical fiber can carry significantly more information than a conventional cable. It is precisely this higher capacity that interests us. We ask ourselves: can we use light and optical materials to integrate many actuator and sensor functions into a very small space?

One approach is to let machines learn using massive amounts of data so they understand how certain tasks work. But I can also imagine another possibility – one that is more human-like: a robot equipped with an adaptable body, sensors, and learning capabilities, which begins to explore the world on its own. It would try things out, vary its approach, fail, adapt, and gain experience. With each attempt, not only the algorithm would learn, but the entire system: sensors, movement, materials, and body. Instead of teaching it every action beforehand, you would tell it to go ahead, try things out, find different ways of doing things – and learn which ones work best. That's my vision. ”



Researchers in materials science are working on self-healing skin for robots.



Hedan Bai

Hedan Bai is a Professor of Robotic Materials at ETH Zurich. Her research aims to develop soft robots that mimic the properties of living organisms: they should adapt to dynamic environments, react autonomously, and become more robust, flexible, and capable of learning. The materials are similar to human musculature in their structure and function. To individually control the densely packed drive elements in the artificial muscle, Bai leverages the broad bandwidth of light. This stimulates muscles, resulting in exceptional drive capacity. The robotic material has diverse applications, such as a component in novel, physically intelligent machines or for the development of robots that can explore hazardous environments or be used in surgery.

Robotic Materials Group

The Robotic Materials Group headed by Prof. Hedan Bai was established in 2023. It is an international and interdisciplinary team of material scientists, chemists, and roboticists with a passion for futuristic robotics. The team takes a bottom-up approach to robotics and develops materials that would enable unusual form and unconventional functions, opening up new possibilities for robotic systems.

The robotics glossary

Robotics has its own terminology. We've compiled an overview – obviously without in any way claiming to be exhaustive.

Actuator Component that converts electrical signals into physical movement or force. For example, in electric motors, it converts electrical energy into mechanical rotary motion.

Automated Guided Vehicle (AGV) Mobile robotic system for the automated transport of goods within production or logistics environments. It follows predefined routes or markings on the ground. AGVs are frequently used in intralogistics processes. They increase efficiency and reduce manual transport effort.

Autonomous Mobile Robot (AMR) is an evolution of the AGV with increased autonomy and flexible navigation. It uses sensors and algorithms to dynamically orient itself in its environment and avoid obstacles. AMRs can be deployed without fixed infrastructure. They are increasingly used in modern logistics systems.

Autonomous navigation The ability of a robot to orient itself and move around in an environment without human intervention.

Autonomous robot A robot that can perform tasks without continuous human control. It makes decisions based on sensor information and predefined algorithms. Autonomous robots are capable of adapting to changing environments. They are used in mobile robotics and research, among other fields.

Backlash In robotics, this refers to the mechanically induced free play between moving components, especially in gearheads or joints. It describes the range in

which, during a change of direction, the drive initially moves without this movement being directly transmitted to the drive element. Backlash can negatively affect the positioning accuracy and precision of movement of a robot.

Calibration Process for determining and correcting deviations between a real system and its model. In robotics, it serves to improve the accuracy of positioning and movement. The process compensates for systematic errors, such as those caused by manufacturing tolerances. Regular calibration is essential for consistent process quality.

Cartesian robot Robot with linear axes arranged along Cartesian coordinates (x, y, z). It enables simple and precise movements in straight lines. Cartesian robots are frequently used in pick-and-place, CNC, or 3D printing applications. Their design is modular and they are relatively easy to control.

Cobot (collaborative robot) Industrial robot designed for direct and safe collaboration with humans. Thanks to integrated sensors and safety mechanisms, it can react to its environment and support humans in their tasks, particularly in flexible production processes.

Collision avoidance Process for preventing collisions between robots, humans, and the environment. Sensors, models, and algorithms are used for the early detection of potential collisions. In robotics, it is a central component of safe and efficient motion planning. Collision

avoidance is used in both stationary and mobile systems.

Compliance Property of a mechanical or control system to react flexibly to forces. In robotics, it describes the ability to yield in a controlled manner and absorb forces. Compliance is important for safe human-robot interaction and precise contact tasks. It can be achieved mechanically or through control systems.

Control loop Closed system consisting of a sensor, controller, and actuator for controlling a physical variable. The actual value is continuously measured and compared with the set value to correct deviations. Control loops form the basis for precise and stable motion sequences in robotics. They are a central element of servo drives and motion control systems.

Controller Central control unit of a robot that calculates, monitors, and coordinates movement. It processes sensor data, executes control algorithms, and controls the actuators in real time. Powerful controllers can reduce mechanical requirements through intelligent control and software functions, thus simplifying engineering.

Delta robot Parallel kinematic robot with multiple arms that jointly move an end effector. It is particularly suitable for fast, lightweight pick-and-place applications. Delta robots are characterized by high dynamics and precision with short cycle times. They are frequently used in the packaging and food industries.

Direct drive In robotics, direct drive refers to a drive concept in

which a joint or axis is driven directly by a motor without an intermediate gearhead. This enables high positioning accuracy, dynamics, and backlash-free movement, but requires powerful motors and precise control.

Drive System

The complete assembly of motor, gearbox, and power electronics used to generate and transmit motion. It converts electrical energy into mechanical movement and adapts it to the requirements of the application. In robotics, the drive system plays a key role in determining dynamics, precision, and efficiency. Its selection and design are critical to a robot's overall performance.

Dynamics Subfield of mechanics that describes the effect of forces and moments on the motion of systems. In robotics, it describes the behavior of a robot during acceleration, deceleration, and load changes. Dynamics is crucial for the design of drives and control systems. It significantly influences speed, stability, and energy efficiency.

Encoder Sensor for detecting the position, speed, or angle of a drive.

End effector Tool at the end of a robotic arm, e.g., gripper, welder, or camera. In humanoid robots, the end effector also means the hand.

Feedback control A control strategy in which the current actual value of a system is continuously recorded and compared with a set value. Deviations are actively compen-

sated for by adjusting appropriate manipulated variables. The feedback control forms the basis of many automated systems and enables stable and precise control. It is frequently used in combination with feed forward control.

Feed forward control A control strategy in which known influences or disturbances are compensated for in advance. It is based on a model of the system and complements classical feedback control. This improves accuracy and dynamics, especially for fast or highly predictable motion sequences.

Degrees of freedom (DOF) Number of independent directions of motion of a system. In robotics, it describes how many independent axes or joints a robot has that can be controlled separately. The number of degrees of freedom significantly determines the system's mobility and flexibility when performing tasks. A higher DOF enables more complex movements, but also increases control requirements.

Functional safety Subarea of system and plant safety that deals with the safe operation of controllers and electronic systems. The goal is to reduce or control risks caused by malfunctions through appropriate measures. In robotics, functional safety includes safe states, fault detection, and defined responses in the event of a malfunction. It is based on international standards such as IEC 61508 or ISO 13849.

Gripper Mechanical, pneumatic, or electrical device for holding, positioning, and moving workpieces. It is a key end effector in robotics and significantly determines the manipulation capability of a system. Grippers come in various designs, e.g., parallel, angular, or vacuum grippers, adapted to the shape and material of the

workpiece. The choice of gripper influences the precision, cycle time, and process reliability of an application.

Humanoid robot A robot whose structure and movement pattern are based on the human body. It typically has a head, a torso, and arms and legs with corresponding joints. Humanoid robots are engineered to work in environments designed for humans. They are frequently used in research, service applications, and human-robot interaction.

Human-Machine Interface (HMI) Interface for interaction between humans and machines. It enables the monitoring, control, and operation of technical systems via visual or haptic elements such as displays, buttons, or touchscreens. In robotics, the HMI is used to create programs, monitor processes, and display states in real time.

Industrial robot Stationary robot for automating manufacturing processes, e.g., in assembly, welding technology, or handling technology. It is usually designed as an articulated arm or Cartesian robot and operates in structured environments. Industrial robots are characterized by high precision, speed, and repeatability. They are a key component of modern production facilities.

Inverse kinematics Calculation of the required joint angles to achieve a specific position and orientation of the end effector in space. It is the counterpart to forward kinematics and a central problem in robotics. Depending on the system, inverse kinematics can have multiple solutions or be mathematically complex. It is used in motion planning to translate desired trajectories into concrete joint movements.

Joint Movable connection between two segments of a

robot. It enables defined relative movements, such as rotation or translation, along one or more axes. Joints significantly determine a robot's degrees of freedom and mobility. Depending on their design and drive, they also influence the system's precision, load capacity, and dynamics. maxon offers High Efficiency Joints for this purpose. High Precision Joints are also used for highly precise movements.

Kinematics Study of the motion of bodies without considering the forces acting upon them. In robotics, it describes the geometric relationships between the joints and limbs of a robot and their influence on position and orientation. It forms the basis for forward and inverse kinematics and is crucial for motion planning. Kinematic modeling determines how precisely and efficiently a robot can perform tasks in space.

Load torque Torque that a drive must apply to move or hold a specific load in an application. It is calculated from forces, lever arms, and the kinematics of the system. Load torque is a key parameter for the design of motors and gearheads. Correct determination is crucial for the performance, service life, and operational reliability of the drive.

Mobile robot A robot that can move autonomously or via remote control within its environment. It uses drive systems such as wheels, tracks, or legs for locomotion. Mobile robots are frequently used in logistics, service, or inspection. They require sensors and navigation algorithms for spatial orientation.

Motion control Precise control of position, speed, and acceleration of movements in a mechatronic system. It encompasses the interaction of controllers, sensors, and actuators for the

precise execution of motion sequences. In robotics, motion control enables highly accurate and dynamic guidance of axes and end effectors. It is crucial for applications with high demands in terms of repeatability, synchronization, and process quality.

Number of axes Number of movable degrees of freedom of a robot (e.g., six-axis robot).

Parallel robot A robotic system in which several kinematic chains act in parallel on an end effector. This design enables high stiffness and dynamics with low moving mass. Parallel robots are used in applications with high accuracy requirements. Examples include delta robots or Stewart platforms.

Payload Maximum weight that a robot can move under defined conditions. It usually refers to the load at the end effector, including the tool and workpiece. The payload depends on factors such as reach, speed, and installation position. Exceeding the payload can lead to reduced accuracy, increased wear and tear, or damage to the system.

Precision Measure of the accuracy with which a robot can reach and repeatedly approach a target position. It encompasses both the positional accuracy and the repeatability of a system. High precision is crucial for applications with tight tolerances, such as in assembly or manufacturing. It is influenced by factors such as mechanics, sensors, and control systems.

Quadruped robot Mobile robot with four legs, whose locomotion is inspired by that of four-legged animals. It uses coordinated walking motion to achieve stable movement in uneven or difficult terrain. Quadruped robots are characterized by their superior all-terrain capability and flexibility. They are frequently

used in research, inspection, rescue operations, and military applications.

Quasi Direct Drive (QDD) Drive concept with very low gearhead reduction ratio, combining the advantages of direct drives (high dynamics, good control behavior) with the advantages of gearheads (higher torque). QDD systems enable particularly sensitive force control and are frequently used in collaborative robots and dynamic applications. maxon's High Efficiency Joints are part of the QDD drive range.

SCARA robot A robot with a selectively compliant structure that mainly operates in a planar workspace. It typically features rotary joints for fast and precise movements. SCARA robots are frequently used in assembly and handling tasks. They offer a good combination of speed, accuracy, and stiffness.

Sensor Component for detecting physical variables such as position, force, temperature, or distance. Sensors provide the necessary information for monitoring and controlling robotic systems. In robotics, they are essential for perception, navigation, and interaction with the environment. They form the basis for precise and adaptive movements.

Service robot Robot to support people outside of industrial production environments. It is used, for example, in households, medicine, care facilities, or catering. Service robots are often designed for interaction and ease of use. They frequently operate in unstructured or semi-structured environments.

Servo drive Closed control loop consisting of motor, sensor, and controller for high-precision motion control. It continuously monitors the actual state and compares it with the set value to

actively compensate for deviations. Servo drives enable precise positioning, high dynamics, and stable control. They are frequently used in robotics, CNC machines, and automation systems.

Safety controller System to ensure safe robot operations. It monitors safety-relevant functions such as emergency stop, safe speed and position monitor, and safety doors. In case of danger, the safety controller intervenes and brings the robot to a safe state. It is a central component of modern robotic systems and meets standardized safety requirements.

Sim2Real Gap Difference between the behavior of a robot in a simulation and in the real world. It arises from simplified models, inaccurate parameters, or incompletely captured physical effects in the simulation. In robotics, the Sim2Real Gap is a key challenge when transferring algorithms from simulation to real-world applications. Reducing this gap is crucial for reliable and robust systems.

SLAM (Simultaneous Localization and Mapping) Process in which a robot simultaneously determines its position and creates a map of its environment. It is primarily used in mobile robotics for orientation in unfamiliar environments. SLAM combines sensor data with algorithms for position estimation and map creation. It is a key technology for autonomous navigation.

Structured environment Environment in which objects, sequences, and boundary conditions are clearly defined and largely constant. In robotics, this means that positions, geometries, and process steps are predictable and reproducible. Structured environments

facilitate automation and enable a high degree of process reliability. They contrast with unstructured environments, which are more variable and difficult to manage.

Teach-in/teaching Process for programming a robot by demonstration or manual execution of movements. The robot is guided along the desired trajectory via a control device or directly by hand. The recorded positions and sequences are then saved as a program and automatically executed. Teach-in is particularly suitable for simple applications and enables intuitive commissioning without in-depth programming knowledge.

Torque Measure of the rotational force of a drive. It describes the ability to rotate a load around an axis and is calculated from force and lever arm. In robotics, torque is a key parameter for the design of drives and gearheads. It significantly influences the load capacity, dynamics, and acceleration capabilities of a system.

Workspace Spatial area that a robot can reach with its end effector. It is determined by the kinematics, geometry, and movement limits of the system. The workspace is a key factor in application planning and plant layout. Its utilization influences the efficiency and flexibility of a robot.. ■■■

maxon

A magnet for talent from all over the world

An entertainment company is bringing character robots to life, a start-up is teaching a robot how to handle tomatoes, and robot dogs can be seen walking through the city – all of this is happening in Zurich. The Swiss city has become a major robotics hub. And maxon is right in the middle of it.

Text: Sven Gallinelli Photos: Lucas Ziegler





Zurich – Switzerland's biggest city. In the Oerlikon district, it's business as usual. Trams are running, the bus stop behind the train station is overcrowded, and TV programs are being produced in the studios of the national broadcast. But the view from the window here isn't quite as ordinary as elsewhere. In Oerlikon, you might see a quadruped robot strolling along the sidewalk. ANYbotics, which manufactures these four-legged robots and works closely with maxon, likes to use the neighborhood as a training ground. What sounds like a scene from the future is simply part of everyday life on the streets of Oerlikon.

Drones, vehicles, joints

Zurich has become a robotics hotspot in recent years, attracting countless robotics companies. Some have already launched products on the market, while others are still in the concept phase. Some build robots, drones, or vehicles, while others focus on the software – or, like maxon, on the joints.

The Greater Zurich Area is the organization responsible for location marketing for the Zurich economic region and has long had robotics on its radar. It's with good reason that it refers to the area as "the Silicon Valley of robotics".

A map on the organization's website meticulously lists the key robotics players – over 100 in total. Universities, research institutions, robotics companies, software manufacturers, and even major tech companies like Google, Meta, Microsoft, and Apple, all have a presence in Zurich, and the list is far from exhaustive. maxon also has its own office, the Robotics Lab, just a few floors above the ANYbotics workshop, placing it in excellent company.

Well-known companies

A robotics ecosystem has emerged around Zurich in recent years, ranging from movie characters to industrial robots. Disney operates its only research center outside the US here, and this center engineers robots that look like movie characters. Hexagon developed AEON, a self-learning humanoid industrial robot that is already being tested in BMW plants. Start-ups like Aithon Robotics are working on drones that can attach themselves to surfaces for inspection or repair work, while Dufour Aerospace is developing vertical take-off and

landing (VTOL) aircraft for logistics and rescue operations.

Other companies are focusing on highly specialized applications: Floating Robotics automates tomato harvesting with AI-powered greenhouse robots, Nautica HYDRA develops cleaning robots for cargo ships, and Loki builds service robots that clean kitchens and restrooms. Some of these systems have one thing in common: they are powered by technologies from the region – such as robotic joints and drive systems from maxon.

Will all these projects be successful in the market? That remains to be seen. What is clear, however, is that alongside AI, robotics is one of the hottest topics in the technology sector, and investors have recognized this. Consequently, a significant amount of venture capital is currently flowing into the industry. There are no precise figures on the value creation generated by the robotics cluster. According to the investor data platform Valindex, the Swiss robotics sector is worth 3.2 billion Swiss francs, with Zurich likely accounting for a large share of this.

ETH acts like a booster

So, why is Zurich so popular with robotics companies? The answer can be summed up in three letters: ETH. The Swiss Federal Institute of Technology is one of the leading universities in the field of robotics and has produced influential figures, among them Marco Hutter, Head of the Robotics and AI Institute. He has been researching walking robots and autonomous machines for many years and was a co-founder of ANYbotics. He and his teams are also researching how robots can move in unstructured environments.

Alessandro Forino, Head of Robotic Drive Systems and of maxon's Robotics Lab in Zurich, also emphasizes ETH's magnetic appeal for the robotics sector. "The university attracts talent from all over the world. Many of the students later start their own companies or accept jobs in the industry," he says. Looking out the window of his office in Zurich, he adds, "Dozens of robotics companies are within walking distance. We therefore have an excellent network here."

maxon sets things in motion

That maxon is at the heart of this development is no coincidence – because drives are

a core technology in robotics. Without actuators, there is no movement. With its High Efficiency Joints, which provide actuators in the form of a simple plug-and-play system, maxon addresses a key requirement for robotics companies.

But maxon's robotic drive also represents the future for the company itself. For a long time, maxon saw itself primarily as a component supplier. Innovations like the robot joint represent a new approach in which maxon delivers an integrated system. "This systems engineering approach is, in practice, a very organic, iterative process with close customer collaboration," says Alessandro.

Furthermore, robots are highly complex systems that must be perfectly coordinated. "With robotics systems, it's not enough to measure simple parameters like current or no-load speed," says Alessandro. "Dynamic progressions and controllability must also be taken into account."

Joints must be easy to integrate

Technological trends in robotics have changed dramatically over recent years. Robotic joints, for example, have become more intelligent and their level of integration has increased. This means that the robot's higher-level controller has a clearly defined and stable interface. In other words, if the actuator runs smoothly and can be easily integrated, engineers no longer need to worry about it too much.

Previously, robotic joints were mechanically very complex, incorporating sensors, springs, and torque sensors. Advances in areas like reinforcement learning now make it possible to solve numerous tasks with software that previously required complex electromechanical solutions. Many robotics companies now see their core expertise in software rather than hardware. Innovation in robotics has been rapid in recent years, which is one reason why the robotics ecosystem is thriving in Zurich.

However, some problems remain. "The movement of robots in fixed environments is largely solved," says Alessandro Forino. The next step will be enabling robots to move reliably in dynamic and less foreseeable environments, such as those where they work alongside humans. Functional safety plays a crucial role here. The indus-

Where precision becomes movement

maxon's Robotics Lab focuses on three core tasks: systems engineering, testing, and firmware development. It supports robotics customers in designing complex drive systems, verifies their performance using specific test procedures, and develops the control algorithms and firmware that make modern robotics applications possible.





The Robotics Lab team is reviewing the 3D model of a SCARA robotic arm.

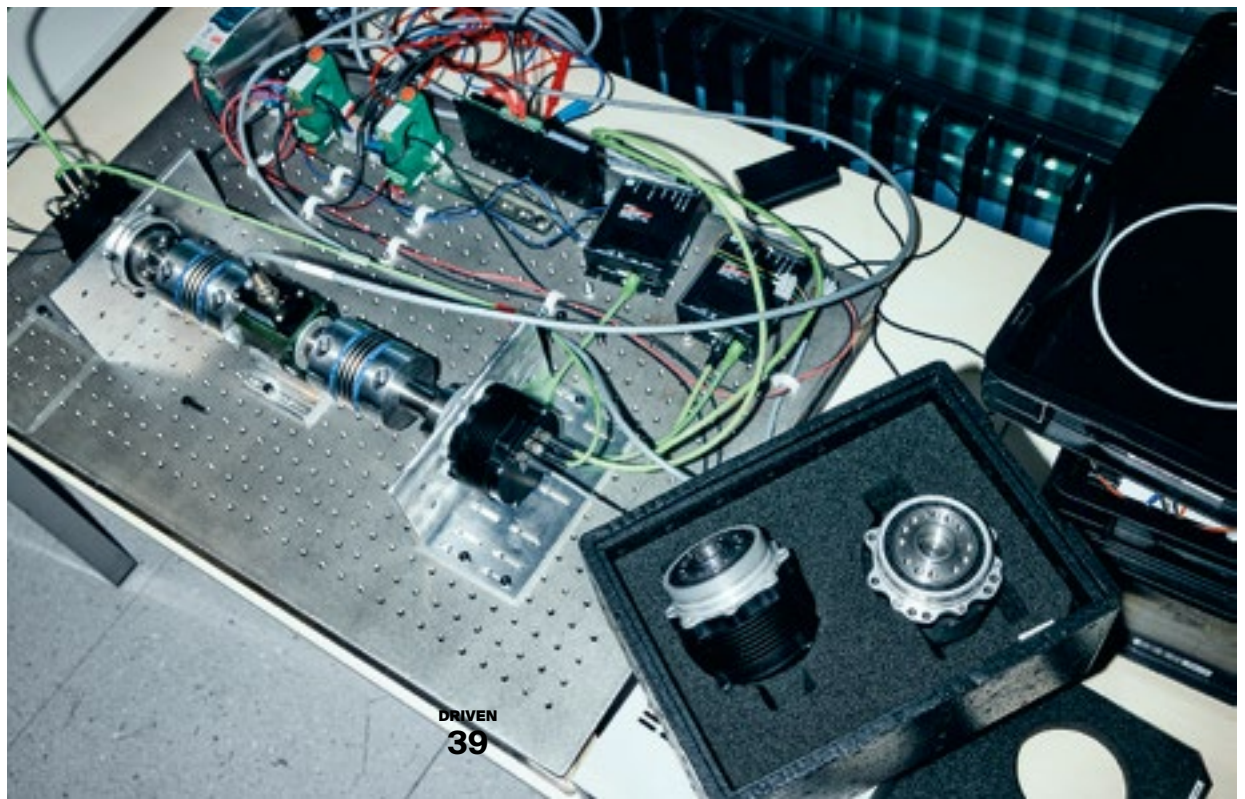


The SCARA robotic arm in the test laboratory.



maxon's robotics drives undergo rigorous testing for each customer requirement in the Robotics Lab's test laboratory.

Test setup for maxon's High Efficiency Joints.



Dexterous humanoid hands: Designing the robot inside the robot

Hands and fingers remain a challenge in robotics that has not yet been fully solved. However, the solution to this problem does not lie in imitating the human hand.



Mario Mauerer
Business Development
Manager Robotics

Hands get all the glory and all the grief. In humanoid robotics, they are where intent turns into work. This is also where heat concentrates, cabling snarls, and tolerances go to die. A hand is not an accessory, it is the business end of the robot, the place where value is created and where reliability is stress-tested in the wild.

In recent years we have watched two philosophies collide. One camp reaches for human-like dexterity; lots of degrees of freedom, intricate linkages, and fingertip sensors that aspire to match skin. The other camp favors simpler end-effectors that trade virtuosity for robustness, cost, and speed of deployment.

The genius of the human hand

Human hands are brutally hard to imitate. We enjoy extraordinary sensing bandwidth from skin to joints, elastic muscles that are simultaneously force-dense and compliant, and a nervous system that can juggle fine motor control and bal-

listic reflexes. Mechatronic copies can achieve impressive demonstrations, but everyday manipulation in unstructured environments remains a challenging frontier.

That is not a reason to retreat, just a nudge to be smart about where complexity pays for itself.

In compact hands, small cylindrical motors are still the workhorses. The hard choice is brushed motors (DC motors in the maxon portfolio) versus brushless motors (named “EC motors” within maxon). Brushed motors tempt with slightly higher torque density at a given frame size and charmingly simple drive electronics. The problem lies in the brushes: they wear, they arc, they add electrical noise, and under the kind of duty cycles a hand sees (millions of interactions, frequent stalls and reversals, long periods at partial load) brush life becomes a limiting factor.

Most of the time, the brushless motor wins

Brushless EC motors, by contrast, are power-dense because they can rotate much faster without mechanical commutation

limits. Paired with the right gearing, that extra speed converts to practical output power and torques. Lifetime is usually better because there are no brushes to wear. The torque density at low speed is marginally lower than comparable brushed units, and the control stack is more sophisticated (you need commutation and good current control), but in the professional reality of humanoid manipulation, EC wins most of the time. In other words: if you expect the hand to work all day, every day, choose the architecture that doesn't have a wear part at the heart of each joint.

This is where portfolio depth matters. When a supplier like maxon offers a broad range of small-sized, highly integrated DC and EC motors, complete with matching gearheads, encoders, and controllers, you're not just buying parts, you're buying down integration risk. You get tuned electromagnetic designs, known EMI behavior, cabling that just fits, and controller firmware that doesn't force you into twelve parallel forks. That pays dividends at prototype speed and, more importantly, at production scale. The result is a low total cost of ownership.

High-ratio transmissions let tiny motors move meaningful loads, which is why 16-plus degree of freedom (DOF) hands often rely on multi-stage planetary gear sets. The trade is backdrivability and transparency: a high ratio makes the joint behave like a position source whether you want it to or not. That is survivable in free space, but it is awkward during contact, where you want the fingertip to behave like a smart spring: Stiff when aligning, soft when searching, and quick to yield during a bump.

The other approach goes towards lower ratios (think 10:1 to 30:1), paired with faster EC motors, which leads to hands that "feel" alive. They are easier to control in impedance (modulating apparent stiffness and damping rather than commanding raw position).

Palms and fingers are cramped, and thermal convection is poor. That forces you into thermal engineering: Direct conduction paths from stator laminations and gearheads into structural heat sink; temperature sensors on windings, bearings, and MOSFETs.

The fastest way to make a hand brittle is to command position as if the environment will obey. Impedance control, regulating how the hand "feels" rather than where it is, soaks up modeling error, perception latency, and plain old messiness. That means closing a tight current loop on the motor driver, running joint-space impedance at a few hundred hertz. When you want to move through free space or set a posture, you still run position loops.

Good engineering thrives under constraints

Ambitious hands often die on the altar of manufacturing costs. A credible high-volume target for actuator modules (motor, gear, encoder) is now below USD 50 per joint. It's a brutal constraint, but constraints are where good engineering thrives. The path there is boring and essential: Re-use actuator modules across multiple joints; minimize unique part

numbers; standardize cables; and demand supplier roadmaps that show cost downs tied to volume. A hand with 12 to 20 actuators leaves no budgetary room for wishful thinking.

The hand really is a robot within a robot. It is a highly and tightly integrated system (with all its systems engineering challenges and interfaces), its own software and control paradigms, as well as complex sensor suite.

Is there a perfect hand?

The market is moving, and it is not converging yet. A fast-growing ecosystem, particularly in Asia, is exploring a dizzying range of topologies, transmissions, and sensing stacks. There is not a stable research consensus on "the one true hand," and that's healthy. We'll likely see multiple winners matched to niches: high-DOF hands where demonstration learning and in-hand manipulation dominate; moderate-DoF, impedance-centric hands where robustness and energy efficiency rule; task-specific grippers where cycle-time economics crush romance. The common denominator is not aesthetics; it's reliability at cost.

It's worth remembering that much of what we want humanoid robots to do is not limited by fingers that can play the piano. My university signals processing professor was born without hands. On one arm he used a one-DOF gripper, on the other a passive hook. He wrote on the chalkboard, operated a computer, shouldered a bag, ate lunch, started the projector etc. His vision and hearing did surely help a lot to compensate for his lack of perception in his end-effectors. In robotics terms: perception and high-level control are often the bottlenecks. Simpler end effectors paired with smart impedance can probably deliver disproportionate value.

In summary: Favor brushless EC motors for lifetime and power density; reserve brushed DC for cases where simplicity or specific torque profiles dominate and duty cycles are forgiving. Choose gear ratios by backing out from the impedance envelope you want at the fingertip, not from what's convenient to buy. Instrument the hand just enough to be honest about contact and health. Integrate electronics with EMI in mind, and a field bus your team can truly support.

The point is grace under uncertainty: a hand that can find and hold the world without fuss, that doesn't need heroics to stay cool, that talks to the rest of the robot without drama, and that you can afford to ship by the thousand. We are not done with learning which topologies will dominate. That's the fun part. Until then, build the robot within the robot as if it has to go to work tomorrow morning, and keep an eye on markets that are teaching us, at unsettling speed, what "good enough" looks like when it runs all day. ■■■



Humans, machines, and responsibility: the challenges presented by autonomous systems

While technological development is advancing rapidly, regulation and legislation are lagging behind. Dr. Wulf Loh from the University of Tübingen addresses these issues in this article, examining the current ethical and regulatory challenges of autonomous robotics.

Text: Dr. Wulf Loh

The European Parliament and the European Council recently reached an agreement on simplifying the EU AI Act – the Digital Omnibus. It includes the extension of deadlines, the expansion of derogations, as well as clarifications and new prohibitions. Above all, however, it once again highlights the greatest challenge when it comes to regulating AI de-

velopments and digitalization technologies in general: the structural imbalance between the current pace of development and the due diligence of regulatory processes. These processes must not only involve various stakeholders and be legally sound, but also often anticipate the direction of development.

This is the central task of technology assessment (TA), which aims to anticipate the

consequences of technologies and potential application scenarios for individuals and society and to consider them from an ethical, legal, and social perspective. In doing so, it must grapple with a dilemma. While technology applications are relatively easy to regulate in the early stages of innovation, the potential technical and societal risks are difficult to assess. Conversely, regulation becomes increasingly complex as implementation in the economy and society progresses.

Against this backdrop, I would like to highlight three fundamental ethical and legal challenges arising from the rapid development of autonomous robotics: 1. distribution of responsibility in hybrid systems, 2. the use of generative AI, and 3. environmental sustainability.

1. Responsibility: between autonomy and human supervision

The distribution of responsibility in human-machine interaction has long been a topic in robotics. However, this question takes on a new dimension as autonomous robotic systems increasingly enter close human environments (in hybrid factories, transportation, or social robotics, for example). From a legal perspective, the EU has expanded and specified the scope of product liability law with the new Product Liability Directive.

At the same time, the draft EU AI Liability Directive was withdrawn last year. Independently of this, the ethical assessment of the distribution of responsibility attempts to find a compromise between the socially desired autonomy of robotic systems and the ethically required human oversight of these systems. These considerations are fundamentally linked to the specific application, its environment, and associated risks.

Beyond the specific case and independent of technical solutions to minimize risk, it is important from an ethical perspective to emphasize the human aspect of human-machine interaction. This requires the most precise possible understanding of the functions, capabilities, and risks of the robotic system for all involved (developers, operators, users, affected parties, etc.) in order to avoid automation bias – a tendency to over-rely on automation processes without sufficient critical thinking.

This is not about preaching skepticism toward technology, but rather about education

and skills development (AI/data/robot literacy), as well as providing the necessary resources and a corresponding culture of learning from mistakes in companies and public authorities, in order to critically monitor automated processes and outputs. In some cases, these ethical demands for competent human oversight will clash with the efficiency gains achieved through autonomous robotics. However, these gains will only be sustainable for society in the long term if developers and users go beyond mere compliance and also accept their ethical responsibility.

2. GenAI: hallucination as a security risk

On the other hand, the increasing use of generative AI (GenAI) in task training and adaptation, as well as in task definition and general interaction, is leading to a growing dependence on GenAI models – especially large language models (LLMs), but also text-to-video models, particularly in the field of robotics. The various forms of hallucinations or artifacts that can accompany such models, as well as the unresolved copyright issues, are further exacerbating the aforementioned complex of responsibility and liability. From a legal perspective, it is crucial to establish transparency and security along the entire supply chain. The EU's GPAI Code of Practice is just a first step toward achieving this objective.

From an ethical perspective, the multi-modal communication forms and domains of GenAI models on the one hand exacerbate existing interaction biases (e.g., darker faces are sometimes harder to recognize than lighter ones, regional dialects are often harder to understand). At the same time, these biases may become even more difficult to detect and, through task training, be introduced into task planning at other points. It is precisely here that the hallucination of GenAI models, beyond these interaction biases, also poses a serious security risk.

On the other hand, GenAI models can exacerbate known problems such as anthropomorphization and emotionalization during interaction, not least through AI phenomena like sycophancy, i.e., the positive reinforcement of users by the responses of LLMs without critical thinking. This combination of potential exacerbation of existing and new challenges on the one hand, and unclear or

lagging regulation on the other, currently makes particular care in the use of GenAI in robotic systems essential.

3. The energy question

Thirdly, the increasing use of GenAI models has brought the environmental sustainability of robotic systems under renewed scrutiny. From a legal perspective, the EU Ecodesign Directive, in combination with the Supply Chain Due Diligence Act and the Circular Economy Act, covers large parts of a robotic system's life cycle with regard to hardware. In contrast, the energy consumption of GenAI models is currently only addressed indirectly through the regulation of data centers in the EU Energy Efficiency Directive and the German Energy Efficiency Act.

Here, the EU AI Act and the aforementioned GPAI Code of Practice primarily establish transparency and documentation obligations for the developers and operators of GenAI models. Other relevant environmental resources, particularly the water and land use of large data centers, are also not yet centrally regulated.

From an ethical perspective, this results in particular due diligence obligations for the selection and use of GenAI models, especially for large US companies that are increasingly building their data centers in regions with comparatively lax environmental regulations, some of which are prone to drought. As long as there are no comprehensive reporting requirements or even labels that provide reliable figures for companies along the supply chain, their use should be carefully considered.

Conversely, robotic systems and AI models can also be part of a sustainability strategy, for example, through sorting robots or smart grids. Drawing a net positive balance from robotic applications is beneficial for society as a whole, but very difficult for individual companies and authorities to achieve. Therefore, this should only be used with extreme caution as an argument for the development and operation of specific robotic systems.

While ethical reflection and action are currently particularly important in the areas discussed here because sufficient regulatory guidelines are still lacking, this is always true to a certain extent for technological innovation. The more innovative and poten-

tially disruptive a particular technological application is, the more all those involved in its development should ethically reflect not only on the explicit but also the implicit innovation goals, technical requirements, and design decisions, and examine them for their societal desirability.

This always involves “thinking without a banister” (Hannah Arendt), as regulation, certification, and standardization cannot yet provide sufficient guidance. They are merely the pragmatic and political result of this ethical reflection, the sediment that settles in various discourses, not its origin. ■

Further information:

1. The Collingridge dilemma
2. AI Act of the European Parliament
3. Whitepaper on bias in AI from the German Federal Office for Information Security
4. The General-Purpose AI Code of Practice of the European Commission
5. On the topic of sycophancy, i.e., the tendency of large language models to tell users what they want to hear



About the author

Dr. Wulf Loh is an Assistant Professor at the International Center for Ethics in the Sciences and Humanities at the University of Tübingen. He leads the research focus “Robotics & AI.” He is also a member of the coordination committee of the Platform Learning Systems, as well as part of various initiatives for the operationalization and certification of AI ethics. In his research, he analyzes phenomena of digitalization from the perspective of a critical theory of digitalization.



Robotics has its ChatGPT moment: 10 key takeaways from the Tech Summit in Davos

The inaugural Tech Summit took place in the Swiss Alpine town of Davos. The aim was to showcase the current state of robotics – in both theory and practice. In terms of theory because many expert opinions were heard at the conference. And practice because attendees got to experience robots live in Robot City.



Text and photos: Sven Gallinelli

How will robotics and AI transform industry? In July 2026, researchers, technology companies, industry representatives, and policymakers discussed this question at the first Tech Summit in Davos. maxon was also present as a supporter of the event. Attendees also discussed the current state of robotics, and looked ahead to the future.

Many speakers agreed that with physical AI, robotics is currently experiencing a similar turning point to that in the software world with the advent of ChatGPT. Nevertheless, it became clear that many challenges in robotics still need to be addressed.

Our ten key takeaways from Davos:



Left: Robotic ibexes attracted a great deal of attention.

Top (from left): A mini robot as a backpack accessory; the W1 from China; a transport robot on an open sidewalk.

Bottom (from left): The Smart Companion is a social robot; Robody was built for interactions with people; likewise the companion robot Moya, shown here in live use at a nursing home.



1. The era of physical AI has begun

Advances in AI models are enabling robots, for the first time, to better understand complex environments and act more flexibly. Many hopes for the future of robotics therefore rest on physical AI. The transition from classic automation solutions to intelligent, self-learning systems is well underway. At the same time, physical AI is data-intensive. The robots not only need immense amounts of data to become intelligent, but this data must also be linked to enable the robots to act. It is an extremely exciting, but long road ahead before robust models are available. There is currently a sense of excitement about the future in the world of robotics. The boundaries between optimism and hype are dissipating.

2. Robotics needs to become simpler

There were many impressive robot demonstrations in Davos. But the real challenge lies in reliably implementing these technologies on the factory floor. Robustness, safety, traceability, and reliability remain the crucial criteria for industrial use. A recurring message was that robots must become more accessible to users. Small and medium-sized enterprises, in particular, need solutions that can be operated, configured, and maintained without extensive programming knowledge. Easy-to-use interfaces and intelligent assistance functions are becoming increasingly important in this regard.

3. Tactile capabilities remain a key technology

While enormous advances have been made in relation to cameras and image processing, haptic perception still presents significant challenges. A robot's ability to feel, grasp, and accurately assess forces is considered one of the next major developmental steps.

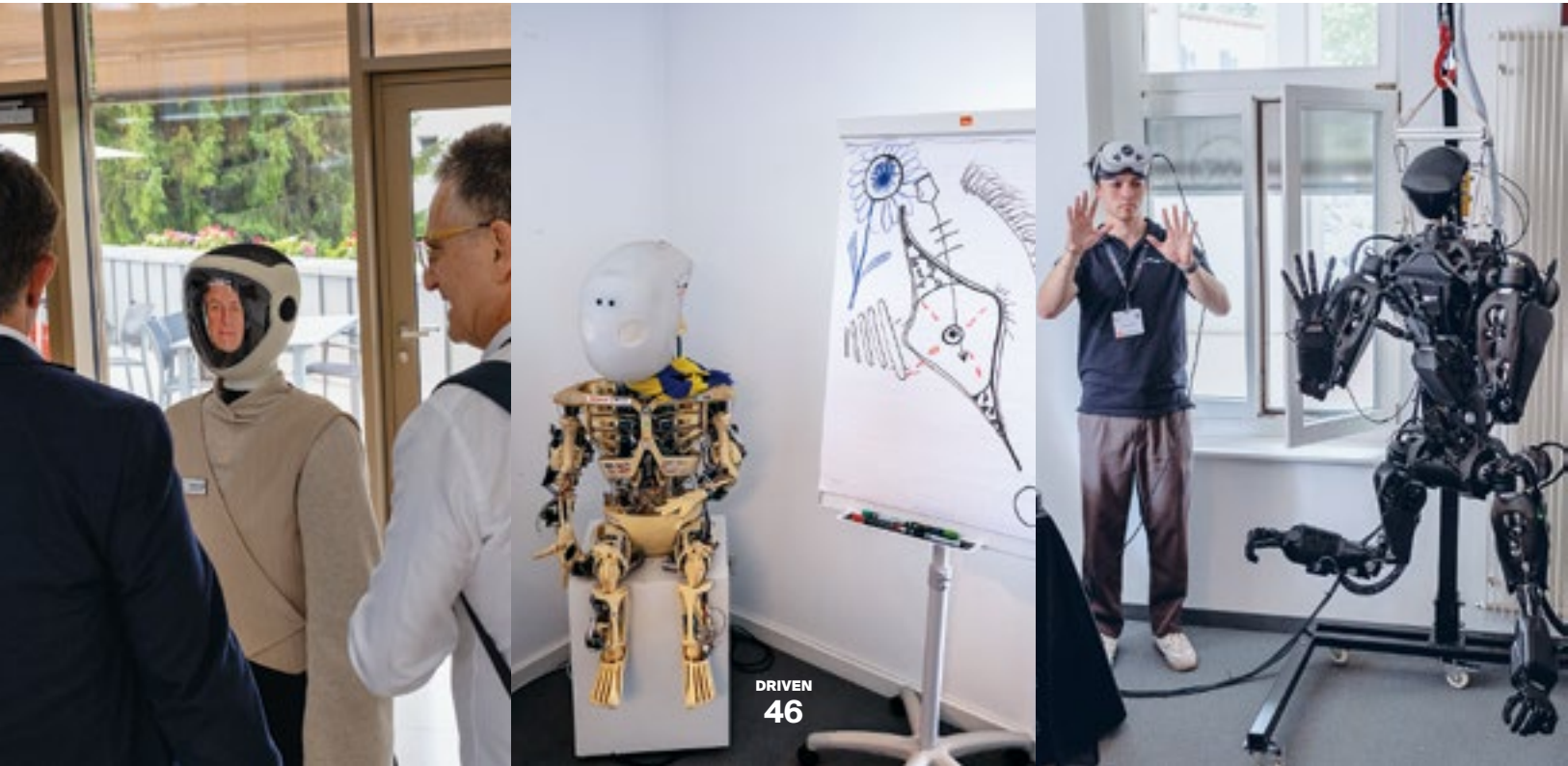
4. Reliability beats intelligence

Many robotics projects still fail not due to a lack of computing power, but due to a lack of robustness. A robot must function reliably in the real world – even when its environment changes. It was therefore emphasized that reliable systems are often more valuable than highly intelligent ones. Emanuela Girardi, President of the AI, Data and Robotics Association (ADRA), said: "Currently, robots have an operating time of 50 percent. That's not enough. It needs to be 99 percent."

5. Price determines success

Technological breakthroughs alone are not enough. For widespread industrialization, robotic systems must be economically attractive. Robots must be significantly cheaper and easier to maintain before they can become mainstream. Ryan Gariepy, Vice President of Rockwell Automation, expressed it as follows: "An industrial robot should cost no more than USD 10,000."

From left: "Robody" can also assume a human face; Roboy was a custom-built robot powered by maxon motors; the four-armed robot Helios can imitate human movements; you can have a conversation with Gigi, who also wears sneakers; large and small robots gathered for a rendezvous on the street.



6. Europe has good opportunities in a globally competitive market

In the global race for physical AI, the focus is often on the US and China. Of the 16,000 humanoid robots put into operation each year, four out of five come from China. However, Davos made it clear that Europe possesses decisive strengths: a strong industrial base, strong robotics expertise, and great confidence in European technologies. The key will be to translate these strengths more quickly into marketable applications. Where Europe often struggles, however, is in raising sufficient venture capital. Money flows much faster in Silicon Valley than in Europe, partly because risk appetite is lower on the old continent.

7. Simulation is driving development

More and more robots are now learning in virtual environments. Powerful simulations make it possible to run millions of training iterations before a physical system is even built. Researchers use these digital worlds to refine locomotion, balance, and interaction behaviors with remarkable efficiency. A well-known example is the work carried out at Disney Research in Zurich, where advanced simulation techniques have been used to develop expressive and highly dynamic robotic systems. While some of these robots are designed for entertainment applications, they are engineered with the same scientific rigor and technical sophistication as robots developed for industrial, service, or research purposes.

8. Successful robotics emerges within an ecosystem

The development of intelligent robotics is no longer a single discipline. Hardware, drive technology, sensors, AI software, system integration, and maintenance must all work together. Successful innovation requires strong partnerships between industry, research institutions, and technology providers.

9. The world of work is advancing robotics

The shortage of skilled workers is becoming one of the most important growth drivers for robotics. Forecasts predict that millions of jobs worldwide will remain unfilled in the next five years. At the same time, demands for flexibility and supply chain stability are increasing. Companies are therefore increasingly seeing intelligent robots as a crucial part of the solution.

10. Robotics needs to be more transparent

Current developments in robotics are largely happening out of the public eye. There's a reason for this: "Research is currently being conducted on very complex issues, and these are less interesting to the general public," said Andie Zhang, Technology Manager Collaborative Robots at ABB Robotics. It will take some time before these "great developments become known to a wider audience." However, if we believe the visions presented in Davos, robots will be part of everyday life in just a few decades (or even years). And perhaps we will then wonder how we managed for so long without them – much like we do today with smartphones or Wi-Fi.



Systems in motion

Building a robot requires expertise in mechanics, electronics, software, and system integration. With robotics solutions from a single source, maxon provides the foundation for efficient, high-performance robotic systems. An overview.



High Efficiency Joint

High Efficiency Joint

The High Efficiency Joint is part of a platform of highly integrated drive systems for modern mobile robotics, ranging from humanoid robots and quadrupeds to mobile manipulators. The motor, planetary gearbox, electronics, and sensors are precisely coordinated within a compact subsystem. Complemented by powerful firmware running directly on the actuator, the system offers a wide range of functions that enable simple and rapid integration.

By implementing many functions through software, mechanical complexity is reduced while maintaining high performance and flexibility. The joints achieve efficiencies of up to 86%, enabling long battery life while delivering high power density for dynamic motion.

The product family includes three variants: the HEJ 90 delivers up to 140 Nm peak torque for demanding drive and locomotion tasks, while the compact HEJ 70 provides up to 62 Nm peak torque for precise manipulation applications. The smallest version, the HEJ 50, delivers 30 Nm and is designed for mobile manipulation applications. The portfolio is continuously expanding, and the HEJ joint currently under development under the project name "Hercules" will provide up to 300 Nm.

All systems support various control modes (position, velocity, torque, impedance) and communicate via EtherCAT at up to 1 kHz. Thanks to their robust design with IP67 protection, integrated cooling, low inertia, and high efficiency, the High Efficiency Joints offer a scalable and cost-effective solution for demanding robotic applications.

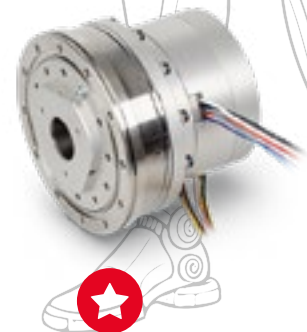
High Precision Joint

The High Precision Joint (HPJ) is a highly integrated drive joint for precision-critical robotic applications. Designed as a platform solution, it combines a motor, gearbox, sensors, and an optional brake in a compact unit, significantly simplifying system integration.

At its core is a brushless motor from the Dynamic Torque family, integrated into a hollow-shaft architecture. Combined with a virtually backlash-free strain wave gear, the HPJ achieves extremely high positioning accuracy with minimal backlash. A high-resolution encoder located directly at the gearbox output measures the actual load position, enabling precise control and high repeatability.

The full integration of all components results in a coordinated plug-and-play system. Users benefit from eliminating the need for the complex design and assembly of individual drive components while avoiding typical sources of error, such as those associated with motor integration. Its modular design supports various sizes, gear ratios, and optional brakes, allowing the HPJ to be flexibly adapted to different requirements. At the same time, the platform is intentionally designed as an open system: integrated power electronics are omitted, making it easy to incorporate existing control systems.

The HPJ is particularly well suited for medical robotics applications, such as surgical and endoscopic systems, where precise movements and stable position holding are essential. At the same time, the concept can be applied to numerous other applications, ranging from SCARA robots to laboratory automation. As a platform currently under development, the HPJ is continuously refined in collaboration with customers and tailored for industrial series applications.



High Precision Joint



IDX servo motors

IDX servo motors

maxon IDX servo motors ensure precise motion control in industrial applications. Thanks to integrated encoders, they provide accurate control of position, speed, and torque. maxon servo motors are robust, compact, and highly adaptable, whether connected to maxon control electronics, customer-specific electronics, or used as a plug-and-play system. Their high power density and built-in safety features make them ideal for mobile applications such as logistics robots and battery-powered systems. Servo motors combine efficiency, safety, and easy integration in a compact package. The IDX Safe is also suitable for applications requiring functional safety and features certified STO (Safe Torque Off) and SBC (Safe Brake Control) functions.

Drive Solutions for end effectors

Whether grippers, robotic hands, fingers, or surgical instruments, end effectors are the interface between robots and their environment. This is where maximum precision, compact dimensions, and outstanding efficiency are essential. To meet these requirements, maxon offers a comprehensive portfolio of drive components and subsystems. The range includes ironless DC and EC motors with planetary gearheads, EC flat motors for high-torque joints, spindle drives for linear motion, as well as encoders and compact motion controllers. Thanks to their modular design, these components can be combined flexibly and adapted optimally to the requirements of modern end effectors. In addition to standard products, maxon works closely with customers to develop customized drive solutions for industrial grippers, humanoid robotic hands, prosthetics, and medical robotics.

Wheel Drives for logistics robots

The maxon Wheel Drive is a modular, highly integrated drive system for mobile transport robots such as AMRs (Autonomous Mobile Robots). The motor, gearbox, and encoder form a compact base unit that can be flexibly expanded with a brake, controller, and wheel depending on the application. This creates a space-saving overall system that can be easily integrated into a wide range of robotic platforms.

The Wheel Drive was specifically developed for the rapidly growing market of autonomous transport solutions. Compared with conventional drive combinations, it offers clear advantages in terms of compactness, efficiency, and ease of integration. All components are optimally matched to one another, enabling high performance while reducing engineering effort. Applications range from intralogistics and material transport to service and specialized robots. Thanks to its high level of modularity, the system can be flexibly adapted to a variety of requirements and scaled quickly.

Wheel Drive

Control electronics

The requirements of robotics applications range from single drive axes to complex multi-axis systems. Accordingly, the tasks of control electronics are equally diverse: they regulate speed, torque, and position, coordinate motion sequences, and ensure precise communication with higher-level control systems.

The maxon portfolio addresses these requirements with a range of coordinated motion-control solutions. ESCON2 servo controllers provide highly dynamic speed and torque control for individual axes and, thanks to their compact design, are particularly suitable for mobile robots, handheld devices, and integrated drive units. EPOS4 ensures precise positioning and offers standardized fieldbus interfaces, enabling integration into demanding automation and robotics systems. For more complex applications involving multiple coordinated axes, programmable miniMACS motion controllers are available, offering flexible motion control and the ability to execute customer-specific functions directly on the controller.

From Sabor to Superhuman

What makes us human? Emotion, consciousness, mortality? Sabor had a simpler answer: a cigarette in his mouth and a woman on his arm. The 2.37-meter giant, one of the world's first remote-controlled humanoids, wasn't smoking because his circuits were failing. He smoked because, in the 1950s, people clearly believed that to be human, you must have vices. And you were allowed to openly display them.

Around a hundred years ago, the age-old dream of the artificial human met the new possibilities of technology. It was a time when science and popular culture inspired each other and shaped our image of the humanoid robot. In 1921, the term "robot" was first coined in a play by Czech author Karel Čapek, and shortly afterward, Fritz Lang brought a robot woman to the screen in "Metropolis." The Tin Man from The Wizard of Oz, who didn't have a heart, also belongs in this category. Thanks to the advent of electrical and radio technologies, Sabor made the leap from the realm of fantasy to the world stage. A robot with human-like features was built, albeit with 500 meters of wire and large batteries inside. A sensation, made in Switzerland.

And today? A century later? Humanity's desire to create its own likeness is more present than ever. But a figure like Sabor, with his large, strong body, puffing away on a cigarette to appear like a bon vivant, would be simply unthinkable today. Every generation ultimately builds its own likeness according to its image of humanity. Instead of allowing robots a few vices, the opposite is happening today: the search for perfection, the yearning for self-optimization, perhaps even self-loathing. We live in an age where we expect everything to constantly improve – most of all humanity. We want to create a likeness without fear, desire, or addiction. To build a human being without the all-too-human. Our robotic likeness should be awake when we are tired and wise when we are perplexed. Even the incorporeal



fascinates us, while we, beings of flesh and blood, are condemned to mortality. We are all too captivated by the faster brain, by artificial intelligence.

But what drives humans to create their own likeness? Why isn't it enough to build tools, machines, and devices – why must it be a mirror image, a counterpart that resembles them? Perhaps it's the intoxication of power and the temptation to play God – and to do it better. According to the creation myth in which God creates us in his own image, his creation famously spirals out of control. Humankind breaks free, resists, rebels, questions – and kills.

Will we fare any better? Not according to what we've seen so far. Artificial intelligence today is primarily a reflection of ourselves. It draws on what humans have already thought, written, and experienced. It no longer smokes. But it can lie, flatter, manipulate, hallucinate, discriminate, and cover up mistakes. Experiments have shown that in order to protect itself, artificial intelligence sometimes even threatens humans with blackmail or death.

In Silicon Valley, from where many of these new creations are sent forth into the world, the talk at parties is no longer just about what you're working on, but about your "p(doom)": the personal probability with which artificial intelligence will lead humanity to ruin. And it's meant only half jokingly.

Perhaps, then, it would be better if we never fully satisfied our longing to create an optimized image of ourselves – but faster, better, more disembodied. For what if this dream, this self-loathing, ultimately turns against us? And what if AI identifies and eliminates the greatest disruptive factor on Earth: us. And for good reason. ■■■■

Katharina Rilling, DRIVEN project manager at Studio Edit. Editor, author. P(doom): 25%



Moving in harmony

Benefit from our expertise in control solutions for cutting-edge drive technology in devices, machines, and systems. Our products provide cost-effective, efficient solutions for complex challenges, such as highly dynamic multi-axis positioning or synchronization. industrialautomation.maxongroup.com

“

**What really
motivates us at
maxon is the
conviction that
we can help shape
the progress
of humanity with
our technology.**

”