

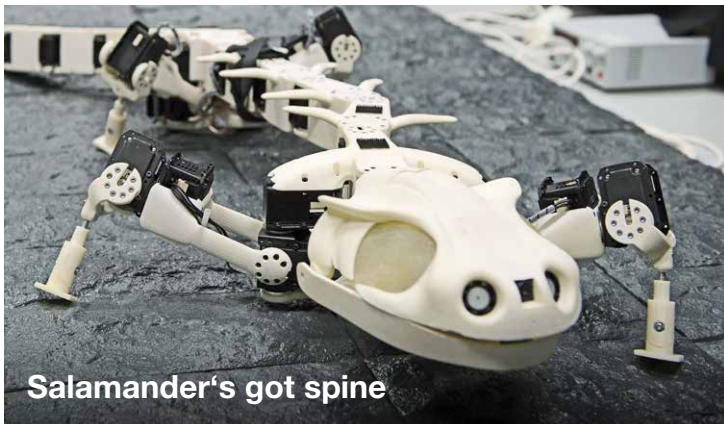


The maxon motor magazine

# driven

## The fruits of research

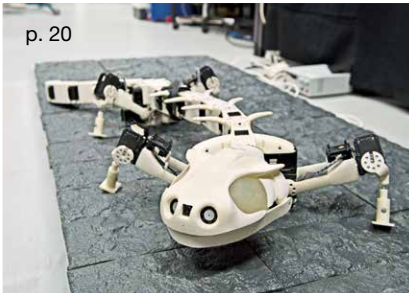
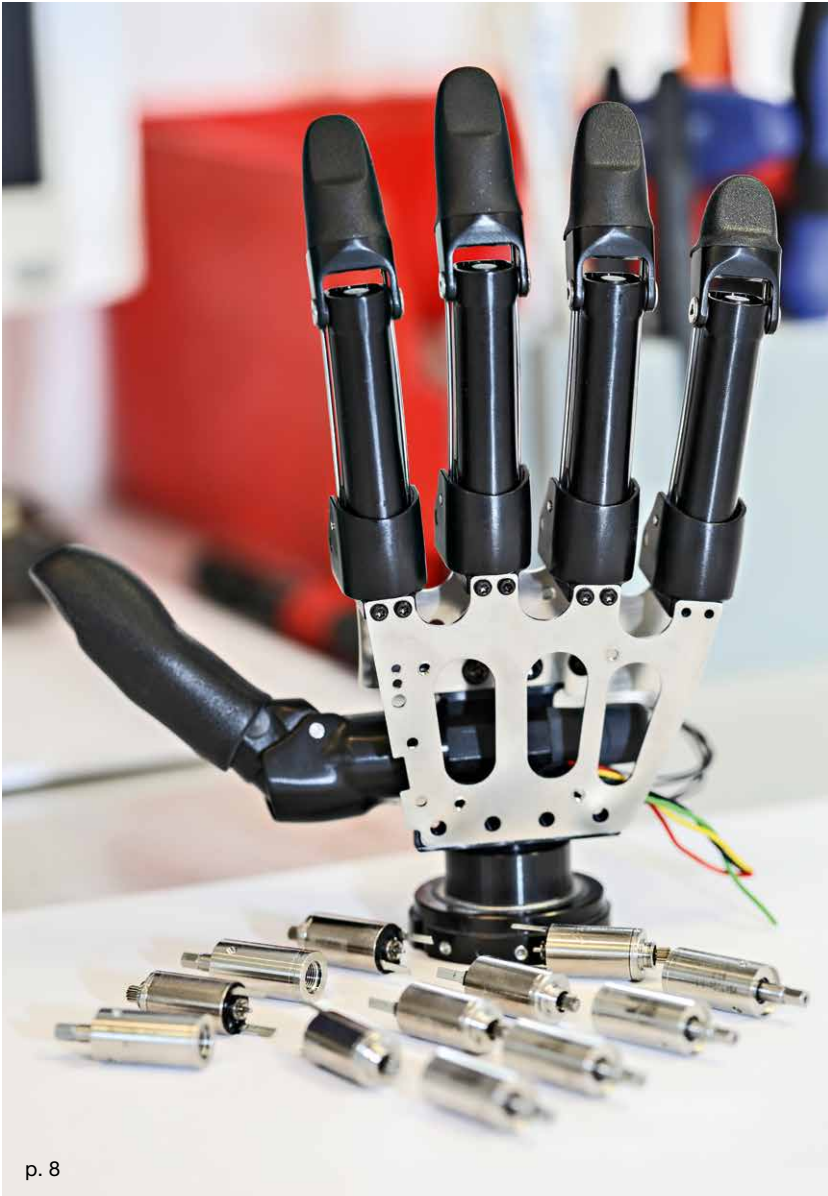
How bionics enables new progress



Salamander's got spine



Olympic champion supports e-bike ambulance



Photos: Karin Mertens / maxon motor, Adrian Bretscher, maxon motor group, Adrian Venetz / maxon motor, Carnegie Mellon University, Stew Wlne, Marsi Bionics, Sbylle Kathriner, Jeremias Wieland / maxon motor

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## How well can we copy nature?



Eugen Elmiger, CEO of maxon motor ag

Engineers frequently use nature as inspiration when they develop new technology. This is because humans, animals, and plants have evolved over the course of millions of years and are perfectly adapted to their respective environments. While we seldom manage to copy the prototypes from nature one to one, we are increasingly getting better at it, as the two impressive examples of hand and foot prostheses in this magazine show.

The driven editorial team has also created a list of the most fascinating current animal robots for you. You will be surprised! Furthermore, you can learn about our successful motion control specialists, how you can use DC motors as generators, and how you can profit from the digitization at maxon in the future.

Happy reading!

# 0.000000001 Meter

That's how big one nanometer is. Or rather: how small it is. In this tiny world, even bacteria seem like giants. It's impossible to construct robots in this size, isn't it? Wrong! Over the past few years, researchers have already demonstrated initial successes in the field of nanorobotics. In a "Nature" journal article in 2017, scientists reported how they are using nanorobots to fight cancer cells directly. However, these tiny devices have very little to do with robots as we commonly know them. They are made of ingeniously assembled carbon molecules, which start to rotate when exposed to ultraviolet light. These molecular motors can then drill through cell walls – at an incredible rate of 3 million revolutions per second. However, it's going to be some time until these nanobots will be widely used in human medicine.



## Growth

### maxon motor sets up manufacturing in the USA

As part of maxon motor's international expansion, maxon precision motors will be opening the doors to a new manufacturing facility in Taunton, Massachusetts. This new production site (5500 square meters in size), will open in November 2018, just 15 miles north of its current Sales Engineering office in Fall River, Massachusetts. The expansion allows maxon to support the growth opportunities in US sales. It will have ample space for offices and a larger warehouse. Over 50 percent of the facility will be a manufacturing area. Manufacturing will continue to produce low-volume product modifications, as this is an ever-growing part of the North American business, but it will also integrate engineering with true high-volume manufacturing capabilities, to serve the markets with value-added products. These capabilities give maxon the ability to even better serve the US customers by offering them faster response times, closer collaboration on the design and manufacturing of custom assemblies, a local supply chain to help reduce costs, and many additional "value-added" opportunities. With a US-based manufacturing facility, maxon is committed to partnering with our customers, building stronger relationships, and contributing to their success.



This is what the new building in Taunton will look like (right). Below is the construction site as it looks now.





maxon Innovation Lab

## maxon motor is moving closer to the EPFL

In May 2018, drive technology specialist maxon motor will be opening the maxon Innovation Lab at the Swiss Federal Institute of Technology of Lausanne (EPFL). The Lab will offer a platform for new technologies and business developments. It will be open for maxon employees, partners, and students. It is located in the Innovation Park of the EPFL, home to around 160 companies and start-ups, which all benefit from the research environment of the university.

maxon motor expects a lively exchange with technology specialists and increased access to current research. The Lab will be available to students as a training platform and offer them opportunities for master projects. Olivier Chappuis, who used to study at the EPFL himself, will head up the maxon Innovation Lab. He says: "I am looking forward to the many

new business ideas and productive collaborations awaiting us in the ecosystem of the EPFL." maxon motor has extensive practical knowledge in drive design and mechatronics, including the fields of robotics, aeronautics, medical technology, industrial automation, and mobility. The drive specialist already opened an Innovation Lab at the Lucerne University in 2017 and is constantly expanding its international academic and innovation network.

maxon is expecting the collaboration with the technology specialists at EPFL to yield new business ideas and access to current research.



Photos: Alain Herzog, maxon motor group

## NEW PRODUCTS

EC 90 flat (260 W)

## The most powerful motor in the family

Maximum torque in the smallest of spaces: This is the new EC 90 flat from maxon motor. The brushless flat motor has been revised and optimized and will be available in two versions from this spring – with 160 or 260 W. The more powerful version supplies an impressive continuous torque of up to 1 Nm, which makes it the maxon drive with the highest torque. The EC 90 flat with 260 W is therefore especially suitable as a direct drive, i.e. without a gearhead. Possible applications include wheel drives, logistics systems, and pumps. In combination with the MILE encoder, this motor is also ideal for positioning tasks.



maxon EC 90 flat  
Ø 90 mm  
260 W, brushless



maxon ECX SQUARE 16  
Ø 16 mm  
brushless

ECX SQUARE 16

## For cost-effective solutions

maxon motor now offers its customers a cost-effective alternative in the field of brushless DC motors. The drive specialist has taken the modern ECX platform as a basis and combined it with a new square housing made from thermoset. The result is the ECX SQUARE 16 L. The motor offers impressively high efficiency, quiet running characteristics, and a long life expectancy. It can also be operated under overload conditions. It is especially interesting for applications such as fans, pumps, or hand-held grinders. If required, the ECX SQUARE 16 L can be combined with the GPX 16 planetary gearhead (1 and 2 stages) and the GPX 19 (3 and 4 stages).

### Online shop

You can find brushless and brushed DC motors, encoders, gearheads, controllers, and accessories in our online shop at [shop.maxonmotor.com](http://shop.maxonmotor.com). You can put your ideal drive together with only a few clicks. The shop also offers comprehensive product specifications and over 6000 free downloads.

# “The world of prosthetics is an engineer's paradise”

A small start-up is set to turn the market for hand prostheses on its head – with an innovative spirit, compact DC motors, and a touch function.

**O**pening the door is only the first of many challenges. A human hand encloses the handle, depresses it, and moves flexibly. In comparison, an electromechanical hand prosthesis is stiff. When the door moves, this results in large forces acting upon individual fingers. “This is why a good prosthesis needs to be made of high-quality materials

“The future belongs to bionic prostheses!”

and components,” Stefan Schulz says, with conviction. He is the founder and CEO of Vincent Systems, a start-up with ten employees in the German city of Karlsruhe. When it comes to hand prostheses, Stefan Schulz is an expert. He built his first electromechanical prosthesis in 1999 while he was still working at the Karlsruhe Institute of Technology (KIT). Ten years later, he moved into the private sector.

Currently, the third generation of prosthetic hands by Vincent Systems is available. “It's lighter and more compact than other models and basically weighs the same as a human

hand,” Schulz explains. The smallest version is even suitable for children – its youngest wearer is only eight years old. The special thing about these hands is that they're bionic. This means that each individual finger is actively driven by a DC motor, and the thumb



Photos: Kammy Ren

Stefan Schulz, CEO of  
Vincent Systems,  
explains how the new  
hand prosthesis works.





maxon DCX 10 S  
Ø 10mm, 1 W,  
precious metal brushes

is driven by two. The motors are installed directly in the fingers and thumb, which makes it possible to replace digits individually. There is something else making the Vincent Systems hand so special: It's the first commercially available prosthetic hand that delivers feedback about grip strength to its wearer. This is achieved with short pulses of vibration. If the hand were to vibrate evenly, a person would quickly get used to the sensation and stop paying attention to it.

#### **“The product will never be perfect”**

Stefan Schulz knows that the task he and his colleagues have set themselves will never be complete. As an engineer, he wants to develop a mechatronic hand prosthesis that

imitates the human hand as closely as possible. “But it no matter how many innovations we come up with, compared to the human original it will always be a compromise. The product will never be perfect; it can always be improved.” However, this doesn't discourage him. On the contrary, it motivates him in his daily work, and it may be one of the secrets behind the success of Vincent Systems. During the short span of the company's existence, the engineers completely revised the prosthetic hand several times, taking into the account feedback by users of the prosthesis and trying new technological approaches. Hearing Stefan Schulz speak, it seems that this wasn't a big deal. As an engineer, he obviously feels comfortable in his field of expertise.

The basic design of most arm prostheses has not changed since the 1960s, when the first models equipped with motors and myoelectric controllers were launched on the market. Two electrodes attached to the wearer's remaining muscles enable them to open and close the gripper. In most cases, only the thumb and forefinger are powered. This design that hasn't changed much for a long time – in part due to the fact that many users were content with these simple functions. In the words of Stefan Schulz: “The world of prosthetics has been in a decades-long slumber, and today it's an engineer's paradise.” While he appreciates the robustness and practicality of simple prosthetics, he is also convinced that “the future belongs to bionic prostheses! We have the technological means, so we should use them to help customers enjoy a higher level of freedom.”

#### **maxon motors deliver that little extra bit of power**

Prosthetics present a significant engineering challenge because of their conflicting design goals: high torque, high speed, compact size, and as energy-efficient as possible. This makes the choice of integrated motors so important. Prosthetic hands by Vincent Systems incorporate up to six maxon brushed DC motors:

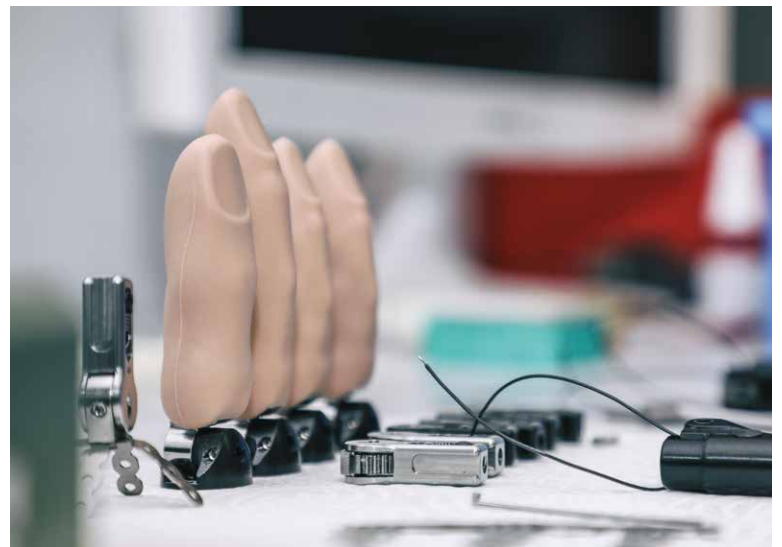
DCX 10 drives, in combination with modified GP 10 A planetary gearheads. “The units are compact, and they are the motors with the highest energy density currently available for our application,” says Stefan Schulz. Moreover, the drives need to be durable and function flawlessly for about five years while being exposed to highly diverse, heavy strain every day. “We are very satisfied, and we plan to further modify the electric motors for our future prostheses in cooperation with maxon motor.”

**Meeting the drive requirements of prostheses is a significant technological challenge.**

Being able to move each finger individually opens up many possibilities for the wearer. 12 grip patterns are available that can be activated fairly easily via muscle contractions – for example by holding a muscle signal or with a double impulse. It was important to Stefan Schulz that patients wouldn't need their healthy hand to help. “A prosthetic hand should help its wearer and not demand the attention of the good hand.”

Most customers need no more than half an hour to learn to control the hand well. Depending on the person, it then takes another few weeks up to a few months to be able to control the prosthesis fully intuitively. After that, the wearer will be able to ride a bicycle, tie shoelaces, hold raw eggs – and open doors, of course. ■

With bionic hand prostheses, each finger can be moved individually.



# The pace-maker

The Empower prosthesis by Ottobock helps its wearer regain lost freedom of movement – using a powerful brushless motor that releases the energy of a calf muscle at every step.

**C**alf muscles are essential for walking and provide most of the energy needed for every step. People who've had a transtibial amputation therefore tire quickly when they walk on prosthetic feet. This makes it almost impossible to keep a normal daily routine – a fact that has long bothered Hugh Herr. After a mountaineering accident, the professor at MIT in Boston had both legs amputated below the knee. Not one to be defeated by this fate, he has spent years tinkering to develop the perfect prosthesis: "Everyone should have the right to walk. We don't have to accept our limitations."

When Hugh Herr finally presented his high-tech prosthesis, the public was nothing short of astonished. His gait was natural, hardly different from any other human. He even performed a quick sprint, something that had previously been considered impossible.

## The bionic prosthesis

In the development of their prosthetic foot, Hugh and his team drew inspiration from nature. He therefore refers to his invention as a bionic prosthesis that combines biology and

engineering in perfect harmony. In practice, it works like this: A powerful motor drives a spring which transfers its energy directly to the foot. This provides the missing power of the calf, step by step with each toe push-off. Several sensors "tell" the prosthesis which phase of a movement it is in at any given time so that it can perform the corresponding action. What's more, the greater the load on the prosthesis, the greater its energy output becomes – just like a natural foot. This allows for short sprints, but also for walking on uneven ground and inclines.

## More than 1,500 prostheses in use

By now the third generation of the prosthetic foot – named Empower – is available on the market. More than 250 people are using it. 32-year old Dylan is one of them. He says: "The Empower takes away my pain and gives me a feeling of having my legs back." Another patient, Larry, shares his enthusiasm: "This prosthesis gives me energy instead of draining it from me. It allows me to remain active all day long."



A powered prosthesis can even be used to walk over difficult terrain, owing to a direct power transfer to the foot and the use of sensors.



**maxon EC-4pole 30**  
Ø 30 mm, 200 W,  
brushless

Over 1,500 people are using Hugh's invention today, if one includes the previous models before the Empower. His small company is now part of the Ottobock Group, the world's leading supplier of prostheses of all kinds. As head of the biomechatronic research group at MIT, Hugh Herr remains in close touch with the Ottobock development team in Boston and is planning to further improve the prosthesis. Wiebke Gellersen, marketing specialist at Ottobock, explains: "We'd like to reduce the installation height and the foot size of the Empower so that we can offer our prosthesis to a wider group of users in the future."

### Doubled battery life

Compared to its predecessor, the Empower is already on a whole new level: A development team spent 16 months refining the energy pulse to make walking feel even more natural. The design was improved too, by integrating the battery into the ankle. At the same time, battery life was doubled.

The active energy is delivered by a carbon spring, which in turn is driven by a powerful brushless DC motor from maxon. The specific model is an EC-4pole 30 – a true powerhouse known for its high output per unit of volume and weight. An ideal ratio between size, weight, and power is a key factor in prosthetics. maxon engineers are familiar with this challenge, which plays a role in a wide range of applications in prosthetics and robot-assisted rehabilitation. Paul Balutis, lead developer for the Empower, says: "maxon motor is a great supplier because they understand the technology of prosthetics."

# A great leap for little legs



EC 45 flat  
Ø 42,8 mm,  
brushless, 70 W



Marsi Bionics develops exoskeletons for children. Because young people are still growing, developing this type of exoskeleton is a great challenge to the skill of engineers.

**W**e've all seen them in action films, comics, and computer games: exoskeletons that give people unimagined powers and equip them with all kinds of technical tricks. Devices that support people's motor systems do not just exist in the realm of fiction – although the real-life exemplars are not quite as spectacular as their Hollywood counterparts. They are made largely for people suffering from paralysis or muscular dystrophy. One of the obstacles is that these technically sophisticated exoskeletons are very expensive. Whether they will eventually make wheelchairs obsolete in years or decades remains to be seen.

Because exoskeletons are usually rigid constructions that move only in the joints, they are predominantly used by adults. There is no risk that the exoskeleton will stop being a good fit. But it's another story with children. An exoskeleton that fits a six-year old like a glove may be much too small by the time the child turns seven. An additional complication for people with muscular dystrophy is that their muscle mass decreases over time – another factor to which exoskeletons should ideally be able to respond.

This is precisely where Marsi Bionics comes in. The Spanish company was created in 2013 as a spin-off from the Centre for Automation and Robotics (CAR), a joint venture of the Spanish National Research Council CSIC, and the Technical University in Madrid. In addition to exoskeletons for adults, the product portfolio of Marsi Bionics also includes two pediatric exoskeletons called Atlas 2020 and Atlas 2030, which can be used by children from 3 years up who are suffering from a neuromuscular disease. The exoskeleton weighs 14 kilograms and can be adapted to various leg lengths and hip widths, so that it also fits teenagers up to about 14 years of age.



The frame helps to maintain balance, but the exoskeleton can also be used without.

### Mobility is retained

As a therapy device, the exoskeleton doesn't only help children walk but can also counteract the progressive loss of mobility – a symptom of spinal muscular atrophy. This is where another special feature of the Atlas 2030 comes into play. The exoskeleton takes advantage of the fact that children with spinal muscular atrophy are not completely paralyzed but are able to move their legs to a certain extent. The Atlas 2030 has sensors that detect weak leg movements and respond immediately to provide support. As a result, the child is able to control the exoskeleton directly with the legs.

"Atlas 2030 is an upgrade of Atlas 2020", explains Elena García, initiator and co-founder of Marsi Bionics. "The main difference is that Atlas 2020 is intended for use in hospitals for gait training and rehabilitation, while Atlas 2030 is designed for use in private homes as an integral part of the patient's everyday life. Both devices are ready for industrial production and will be made available commercially once they have received their CE certification marks. Until then, Atlas 2020 will continue to be used in hospitals for clinical research."

### Powerful and space-saving

A part of this piece of Spanish engineering art was contributed by Swiss drive specialist maxon motor. Five EC 45 flat motors are used on each leg of the exoskeleton. The brushless flat motors deliver very high torque in a compact design. Inductive MILE encoders act as sensors, and the motors are controlled by servo controllers from maxon's ESCON series.

"EC flat motors provide the best power-to-weight and power-to-volume ratio", explains Elena García. "This is a variable of paramount importance, as gait exoskeletons require high power but a very low weight and volume. This is an aspect that still needs improvement." ■



# Fauna Robotica

In millions of years of evolution, nature has produced many sophisticated locomotor systems that engineers use as inspiration for creating better robots. We show some current technical developments that are highly advanced.

## The bionic bird

It might only be a toy, it's anything but ordinary – the Bionic Bird not only looks like a bird, it also flies like one! A French company developed the Bionic Bird, which can be controlled with a smartphone. It achieves a speed of up to 20 km/h and has a range of 100 m. Its developers have been dreaming of an electrically driven bird for a long time, but it was only after the rise of light micro-technology that this vision could become reality. And now the Bionic Bird, which weighs only 9 g, is a fascinating alternative to the customary propeller drones.

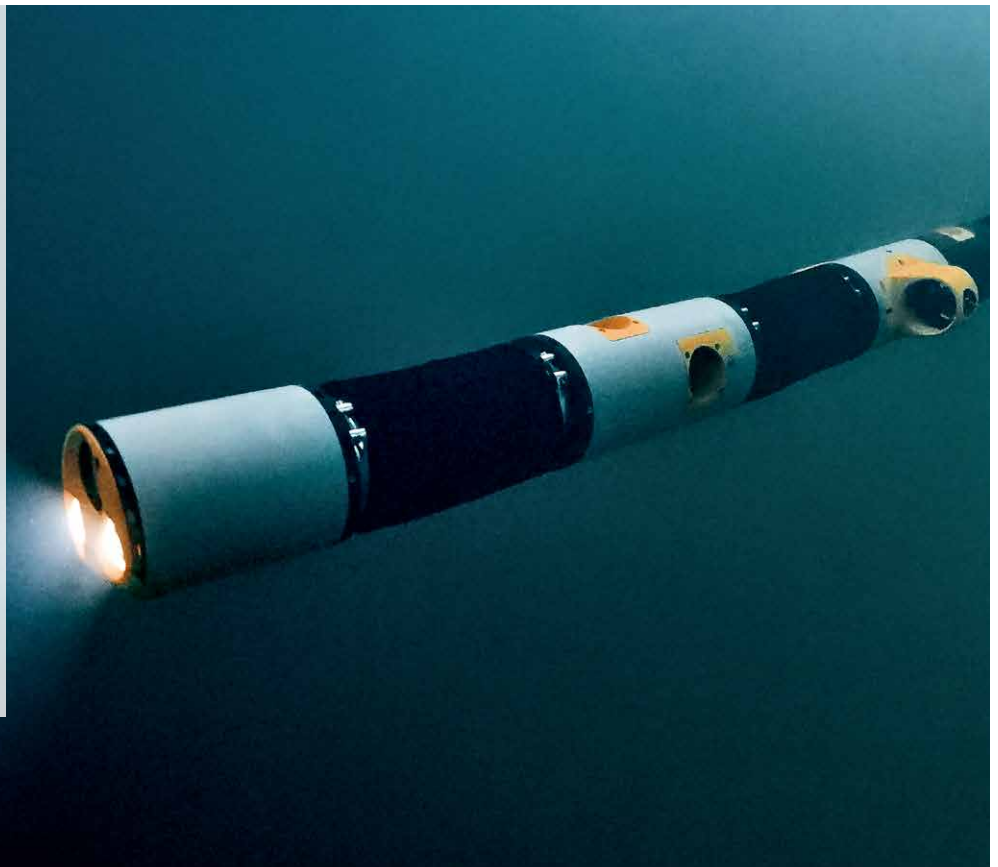
Photos: Bionic Bird, ETH / ANYbotics, Eelume

**ANYmal**

In 2009, engineers at the Robotics Systems Lab of the ETH Zurich started to develop a four-legged robot that can move autonomously and is intended for use in harsh conditions. ANYmal is now capable of running, conquering inclines, and even pressing the elevator button. With laser sensors and cameras, the robot continuously creates a map of its environment, knows where it is and carefully navigates through the terrain. ANYmal weighs around 30 kg, can carry a payload of up to 10 kg, and runs for two hours on a single battery charge. It is being distributed and further developed by the ETH spin-off ANYbotics. In the future, the robot, which is able to run, jump and climb, could be used for inspections, rescue operations, or in entertainment.

**The underwater snake**

The Norwegian start-up Eelume has developed a modular underwater robot in the form of a snake, for use in inspections, maintenance, and repair work. The slimline, flexible body of the robot can cross vast distances and also reach places that aren't accessible to conventional underwater robots. The engineers have been working on the snake robot for ten years and keep on developing it further. The plans for its future include keeping it on the bottom of the ocean indefinitely, at a docking station from where it can launch into action whenever needed. The underwater snake is currently still dependent on a cable. But it is already flexible and its moving connecting parts make it possible to use the snake as robot arm with mounted tools. maxon motor supplies brushless DC motors combined with customized gear-heads for the connecting modules.





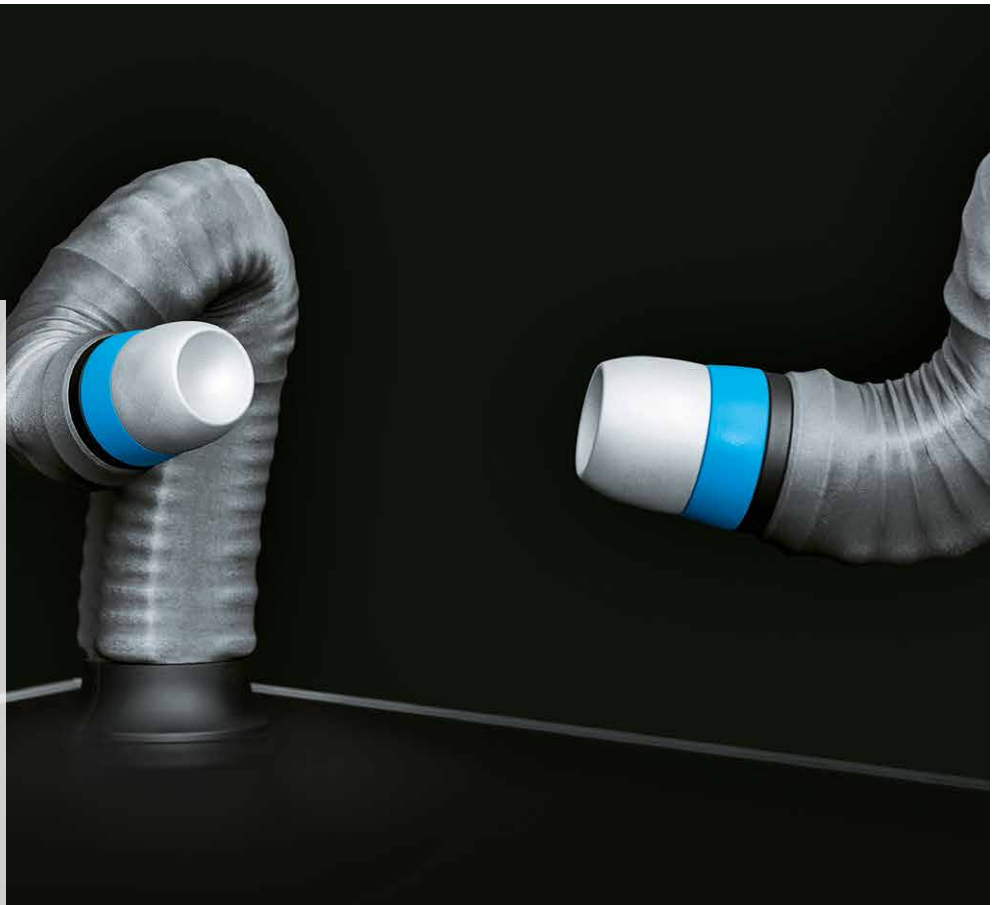
#### The robotic snake

This robot not only looks like a snake, it also moves like one. Its independent modules enable the SnakeBot to climb up pant legs and lamp posts. Its small diameter of 6 cm enables it to crawl into narrow cracks – for example after major earthquakes. It was developed by the Carnegie Mellon University in Pittsburgh (USA) and has led to the founding of the start-up HEBI Robotics. The current modules contain EC-flat 20 brushless flat motors by maxon. These drives deliver high torque and can withstand short periods of overload, which is an advantage in this application. Per snake, approx. 20 modules are used. They are now also being combined into other “animals.”

Photos: Carnegie Mellon University, Bionic Bird, Festo

### Octophant

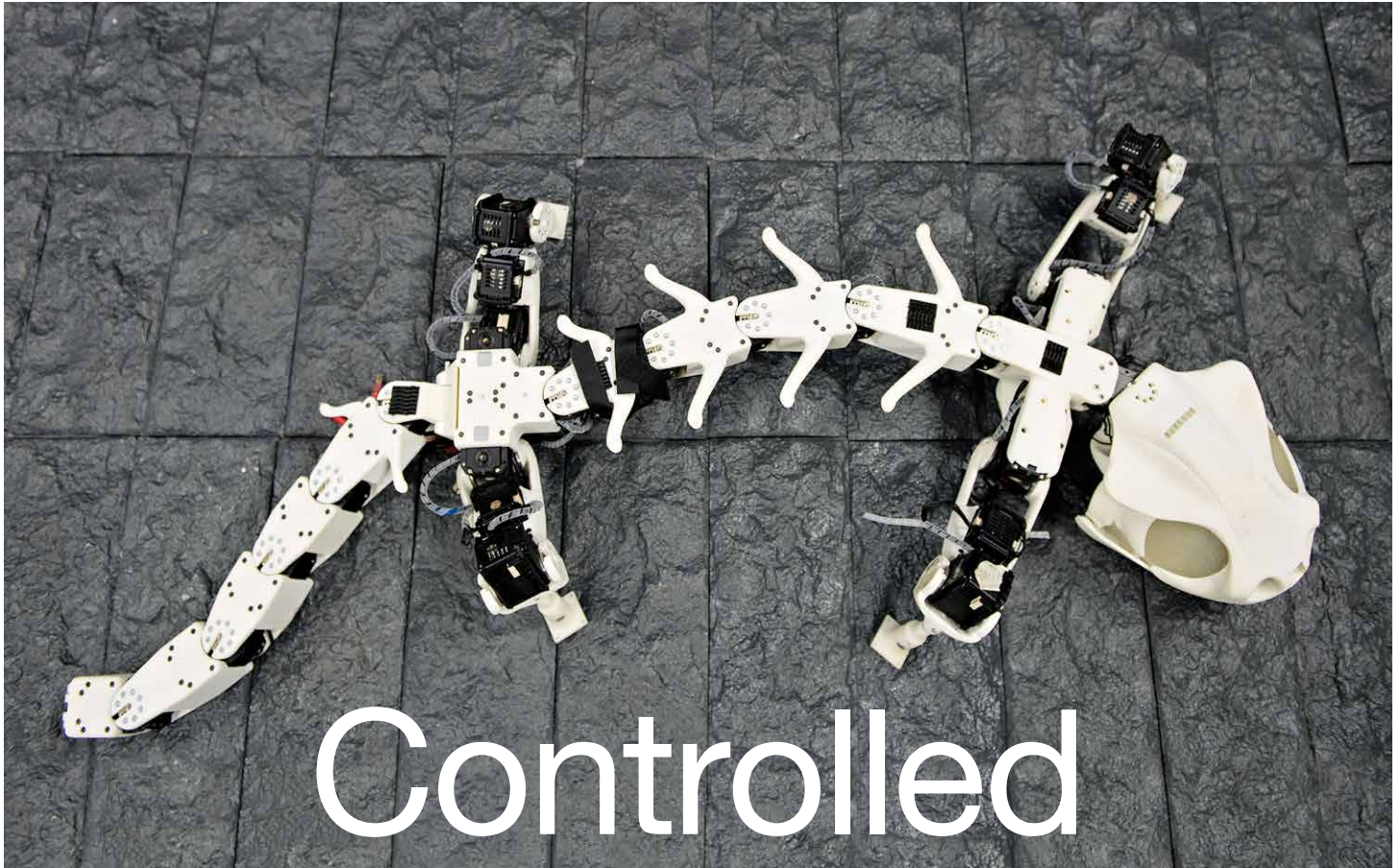
Time and time again, the engineers at Festo present astonishing bionic concepts for the cooperation of humans and robots. That also holds true for one of their newest developments: The BionicMotionRobot. It is modeled after an elephant's trunk and an octopus's tentacles. The result is a pneumatic lightweight robot with twelve degrees of freedom that can carry a payload of three kilograms. Like the natural role models, the BionicMotionRobot offers flexible movement and can bend in three different directions at the same time. According to Festo, a skin made of innovative fiber technology inspired by the muscle fibers in an octopus's tentacles makes it possible to exploit the full power potential of the kinematics.



### Contest

Don't have  
a bird yet? Then join  
in on page 38.





Photos: Sibylle Kathriner, iStock / DavidHCoder

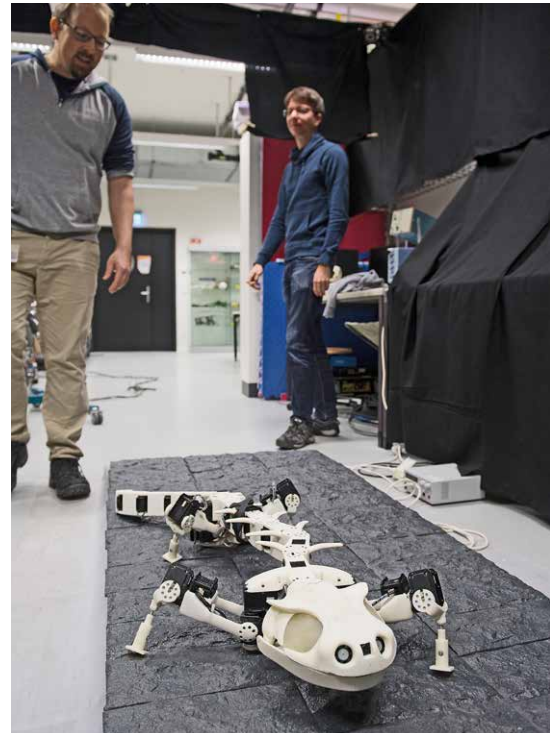
The spinal cord is a miracle of nature, and it is a long way from being fully understood. At the Swiss Federal Institute of Technology in Lausanne, a team is building robots to explore the secrets of the spine.



**Auke Ijspeert** is a professor at the Swiss Federal Institute of Technology in Lausanne (EPFL) and the head of the Biorobotics Laboratory (BioRob). He studied physics and holds a PhD in artificial intelligence from the University of Edinburgh. His research interests lie at the intersection between robotics, computational neuroscience, non-linear dynamical systems, and applied machine learning.

**B**rushing teeth, making coffee, unlocking a door – our brain is the central processing unit for many physical movements. This might make you think that without the brain, nothing would happen at all. But that's not quite true. When a doctor uses a small hammer to tap our knee, we experience a reflexive kick of the lower leg. And when we accidentally touch a hot stovetop, our hand will jerk back immediately. It's not the brain that's responsible for such movements, but another part of the central nervous system: the spinal cord. A headless chicken is, albeit somewhat morbid, proof of the fact that a living creature is able to move without a brain. The chicken flaps and runs about for several seconds even after its head has been severed from the body.

But how do these motor circuits in the spine work? What are the underlying control mechanisms for the movement of vertebrates? This is just one of the questions investigated by Auke Ijspeert's team of 17 at the EPFL in Lausanne. The scientists chose a somewhat unusual approach for their research – they're



Peter Eckert (left) and Simon Hauser present the Pleurobot in the Biorobotics Laboratory.

building robots. That also explains the name of their work place: Biorobotics Laboratory, or Biorob for short. "We use robots as a scientific tool to help us better understand mobility in living beings," explains Auke Ijspeert. It's not so much about building a robot that looks spectacular or is able to work autonomously: "With our robots, we want to contribute to research in the neurosciences and biomechanics." Evolutionary biology also benefits from the team's work. "In many animals, motor control happens mostly in the spinal cord. I find that fascinating."

The Pleurobot by Auke Ijspeert and his team attracted particular attention. What at first glance looks like a paleontological skel-

eton assembly kit is actually a sophisticated reproduction of a salamander's musculoskeletal system. Watching the Pleurobot, which is powered by 27 motors, move in water or on land leaves the observer in awe. The similarity to a salamander's natural movement is remarkable. The Biorob team made every effort to design the Pleurobot to be as similar to a salamander as possible: They used 3D X-ray videos to analyze every limb of a salamander in motion. This was followed by meticulous mechanical and motor function calculations.

### The brain does not have sole control

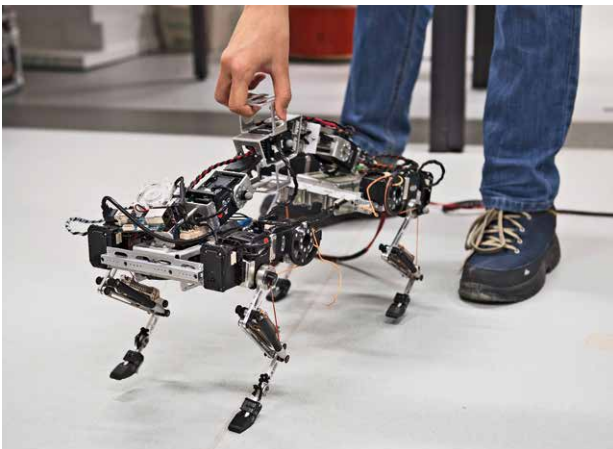
It's no coincidence that biomechanical research focuses on amphibians. Their locomo-

tor system is interesting because it permits studying the gradual transition of movement on land and in water. Several years ago, neurobiologists were able to show that salamanders can be "remote controlled" by stimulating their spinal cord. Weak electrical stimulation lets the salamander walk; increasing the stimulus beyond a certain threshold results in the salamander performing its typical swimming movements. This ultimately means that the salamander's brain is not fully in control of the locomotor system. In fact, the spinal cord and limbs form an almost autonomous control and locomotor system. "The brain merely has a stimulating function," says Auke Ijspeert. The Pleurobot follows this functional principle: Transitioning from walking to swimming movements requires only an increase in the electrical current. "When we control the Pleurobot remotely, we don't need to control each individual motor. Similar to the brain of a salamander, we only determine the direction, the speed, and the intensity of the stimulus." The function of the spinal cord

in the Pleurobot is assumed by a microcontroller which – put simply – has been programmed with mathematical models of a salamander's spinal neural network.

But why go to all this effort? "Our interest is to fundamentally understand how the nervous system in a spinal column functions," explains Auke Ijspeert. It's a very complex subject that has by no means been exhaustively researched. The spinal cord's well-protected location in the canal of the vertebral column in particular makes it very difficult to measure its neuronal activity – even more so than the activity of

**In many animals, motor control happens mostly in the spinal cord.**



The four-legged robot "Serval" is used to study catlike movements. Its legs are specially designed with springs, for better adaptation to the surface.



In the Biorobotics Laboratory, robots are being developed as a scientific tool to allow us to better understand the movement of vertebrates.

the brain itself. “You can’t just stick some electrodes into the spinal cord of a moving animal and measure what’s happening.” One reason why Auke Ijspeert likes this combination of biology and robotics is that other scientific disciplines benefit from it. A fundamental understanding of movement can help in the manufacture of neuroprosthetics, for example. Discoveries in the fields of neuronal systems and the spinal cord are incorporated into research work on new paraplegia therapies.

With its Envirobot – a snake-like swimming robot – the EPFL team have also developed and built an inspection robot. It can be used to detect and measure water pollution, for example.

But Auke Ijspeert’s team researches much more than amphibian robots. A cat-like robot named Cheetah and humanoid robots are also part of the lab’s inventory. For many of its projects, including the Pleurobot, the Biorobotics Laboratory uses DC motors from maxon. The modular Dynamixel actuators by Robotis are used mainly in robotics projects. These modules mainly incorporate maxon RE-max motors, the tried and tested brushed motors with an ironless winding. Auke Ijspeert compliments the Swiss drive specialist: “We like maxon a lot!”



## What makes a system intelligent?

In drive system planning, motion control is a topic that needs to be addressed sooner or later. Fortunately, maxon has a competent team that takes care of all questions related to controlling motors.

**W**hat would a motor do without control? Exactly: Almost nothing. With a only a power source, you can get a brushed DC motor to turn – but that's about it. In the countless highly specialized applications in which maxon motors are used, precision control is the backbone of the system. Yet sometimes

it is almost forgotten that maxon not only develops and distributes motors and gear-heads, but also the matching controllers – in a dedicated department called Motion Control. “Yes, sometimes we do feel a little let down when people always write about the motors and never about controllers,” says



One of many controllers:  
the ESCON Module 50/8  
motherboard



Compact and reliable:  
an EPOS4 controller

Patrik Gnos, the head of the department. Then he adds grinning: “This also gives us an additional push to surpass ourselves.”

In 2017, maxon sold 843,000 controllers, 70 percent more than the year before. This sharp increase is largely due to a manufacturer of large diesel engines, to whom maxon supplies special pump systems – consisting of motor, electronics and software – for the reduction of harmful emissions. About 1.3 million units of these small pump systems have been sold so far. Because the engineers at maxon succeeded in significantly reducing the manufacturing costs of the drive system, the order quantities skyrocketed. “Of course that makes us very proud,” says Patrik Gnos. 45 people are working in the Motion Control department today – electrical engineers, mechanical engineers, physicists, computer scientists. A lot of their work revolves around the topic of control algorithms. What does that mean?

An algorithm is a work instruction, i.e. a clear sequence of commands for achieving a specific goal. The recipe for a cake is a good example of an algorithm. Such algorithms can

be cleverly constructed – or not so cleverly. Example: When baking a cake, you could mulishly perform each step by itself, without thinking of the next one. However, you would waste a lot of time and end up with chaos in the kitchen. For example, it would be clever to preheat the oven before the dough is ready, or to clean up while the cake is in the oven. Drive systems also need software with work instructions for the hardware. And the smarter the programming of the control algorithm is, the more reliable and efficient the system will be. In ideal cases, smart programming may even eliminate the need for additional hardware, such as sensors. “This is where we come in with our know-how,” explains Patrik Gnos. “An algorithm brings intelligence into a drive system.” And in the Motion Control department, optimizing algorithms is a constant task. “When customers get the feeling that we are providing them with the perfect controller, we’ve already spent a lot of time thinking about how to improve it even further.”

The Motion Control team is in a constant exchange of information with our customers. “This consulting service is one of maxon’s greatest strengths,” says Patrik Gnos. It is divided into presales support and after-sales support. Here’s a typical case in pre-sales support: “The customer tells us about the required functionality for their drive system. Then we help them to choose the right controller,” explains Patrik Gnos. maxon continues to support customers after they have purchased their drive systems. “This can be about something very simple – like a cable that’s plugged into the wrong jack.” Or maybe the integration into a higher-level controller is not working as desired. “This is why it is extremely important to us to consult with and support our customers before they order a product.” This support by maxon is highly valued all over the world.

From a manufacturer of components to a systems provider: Patrik Gnos is very happy with the path maxon motor has taken. For more than 20 years, he has been an advocate for not just selling individual components, but to instead offer tailor-made drive systems. With a laugh, the head of the Motion Control department adds: “I’d love to change the name, too: Just maxon instead of maxon motor. Because maxon can do so much more than build motors.”



Head of Motion  
Control Patrik Gnos in  
discussion with  
his colleague Markus  
Stoop.



Photos: Adrian Bretscher

# Actions speak louder than words

In a medical emergency, every second counts. But if the hospital is a long distance away over sandy roads, then you have to think outside the box. In Mozambique, e-bikes are a possible solution – tested by the world's best mountain biker.



**T**here isn't much that Swiss rider Nino Schurter hasn't achieved on a bike. He's a multiple world champion, an Olympic gold medalist, and probably the best mountain biker in the world at the moment. And yet he is deeply impressed by his visit to a small village in Mozambique, in southern Africa, where residents use bike trailers to transport pregnant women and other patients to the closest health center – on dirt roads. "I'm an elite athlete, but even I would find it hard to pull

the heavy trailer with the patient on it," says Schurter. That's why the health organization SolidarMed teamed up with maxon to retrofit two of the ambulance bikes with maxon BIKEDRIVE kits. A two-year pilot phase will now demonstrate whether the e-bike can prove its worth.

Nino Schurter is supporting the e-bike ambulance. The project is clearly close to his heart, which is why he is making an exception in Mozambique and riding an e-bike for once,



to pull the heavy trailer. After all, he wants to find out what the ambulance is capable of. His initial assessment: “The motor is robust, but the quality of the bike isn't good enough yet. It's only a matter of time until repairs will be due.” The project leader for the e-bike ambulance on site is grateful for the tips from the world's top cyclist, as the prototype will undergo continuous development until the end of 2019. If the project is a success, SolidarMed would then like to expand the e-bike ambulance project to cover the entire region.

The visit to Mozambique has made a strong impression on Nino Schurter. “The landscape is beautiful, and the people are extremely friendly and cheerful.” He seems particularly touched by a bicycle race organized in his honor by locals, where he is the star participant – in this case, without a motor.

maxon BIKEDRIVE is supporting the SolidarMed E-Bike Ambulance Project with two retrofitting kits, each comprising

a motor, battery, and Powergrip. The maxon BIKEDRIVE, which can be installed on almost any bike, is currently only available in Switzerland. Germany will be added in the near future. ■

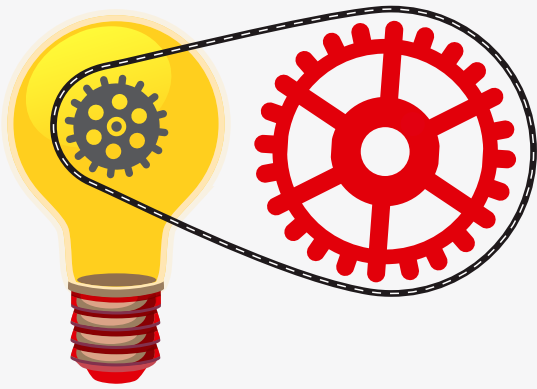
[www.maxonbikedrive.com](http://www.maxonbikedrive.com)



Residents of a small village in Mozambique are organizing a bike race for Olympic gold medalist Nino Schurter.

# DC motors as generators

Both brushed and brushless DC motors can be operated as generators. However, there are some important points to consider when designing the drive, as Urs Kafader, head of maxon Academy, explains.



**E**very now and then, I'm asked about the suitability of maxon DC motors for use as a generator. Since our motors are very efficient, this is also true when operated as generators. The basic calculations between speed and voltage as well as current and torque are very simple. In the following, a few rules for a successful selection.

## DC or AC voltage?

### Rule #1

For generation of DC voltage, select a brushed DC motor or use a brushless EC (BLDC) motor with voltage rectifier. For the generation of AC voltage, select a brushless EC motor and connect 2 phases only. Hall sensors are not needed on brushless motors.

## Speed constant $k_n$

Many generators are operated at speeds of 1000 rpm or below. That's quite a low speed for small motors. Generating 10 V or more at 1000 rpm requires a speed constant of only 100 rpm/V or less. Such windings are hard to find in the maxon portfolio. There are only a few high resistance windings on larger motors that satisfy this requirement. Smaller motors have higher speed constants.

Table 1 shows a selection of motors with low speed constant (or high generator constant = generated voltage per speed). Usually, it's the motor winding with the highest resistance only that results in a speed constant of less than 100 rpm/V.

### Rule #2

Without considering the load, the winding should have a speed constant of  $k_n < \frac{n}{U}$  or smaller.

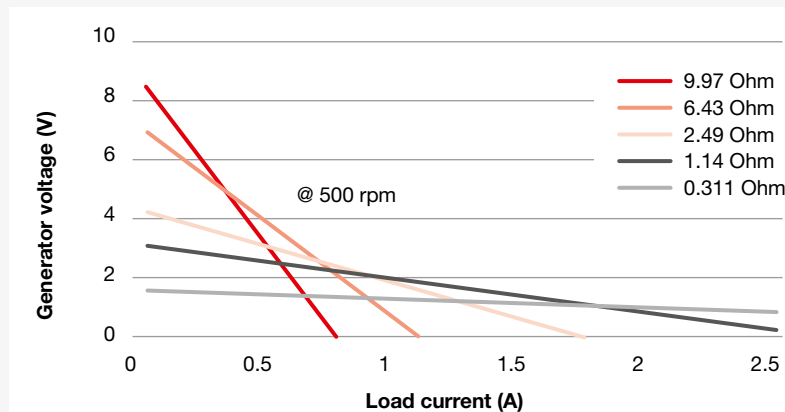
As an alternative, the motor speed can be increased by the use of a gearhead (see next page).

## Resistance

Rule #2 requires motors with high a generator constant. Unfortunately, their windings have the highest resistance as well. High resistance reduces the output voltage under load, and the output voltage becomes very sensitive to the load current.

Motor typ	speed constant $k_n$	voltage per 1000 UpM	terminal resistance	Remarks
DCX 32 L	97.9 rpm/V	10.2 V	4.1 $\Omega$	winding with lowest $k_n$
DCX 26 L EB	111 rpm/V	9.0 V	11.6 $\Omega$	winding with lowest $k_n$
RE 50 GB	39.5 rpm/V	25.3 V	3.9 $\Omega$	winding with lowest $k_n$
RE 40 GB	56.2 rpm/V	17.8 V	10.2 $\Omega$	lower $k_n$ available
RE 25 GB	97.8 rpm/V	10.2 V	36.8 $\Omega$	winding with lowest $k_n$
EC-max 40	76.1 rpm/V	13.1 V	7.2 $\Omega$	winding with lowest $k_n$
EC-i 40 HT 70 W	104 rpm/V	9.6 V	2.0 $\Omega$	winding with lowest $k_n$
EC-i 40 HT 100 W	104 rpm/V	9.5 V	0.9 $\Omega$	winding with lowest $k_n$
EC-flat 45 50 W	95 rpm/V	10.5 V	7.5 $\Omega$	winding with lowest $k_n$
EC-flat 45 70 W	72.7 rpm/V	13.7 V	6.9 $\Omega$	winding with lowest $k_n$
EC-flat 60 100 W	83.4 rpm/V	12.0 V	1.1 $\Omega$	winding with lowest $k_n$

Selection of maxon motors with low speed constant.



The voltage-current lines of the different windings of the RE 40 with precious metal brushes at 500 rpm. Observe the different slopes of each winding.

#### Rule #3

For stable output voltage over a certain load range, select a larger motor where the resistance is lower even on motors with high generator constant. The EC-i 40 High Torque motors are very interesting from this point of view.

#### Power restrictions

Do not select the motor-generator on power considerations alone. In order to fulfill the torque requirements, you might need a motor with a much higher power rating than the

generated power; in particular if the generator speed is rather low compared to typical motor speeds.

#### Torque and speed limitations

The amount of torque on the generator defines the size and type of the motor-generator. Select a motor type with a continuous torque higher than the generator torque.

When calculating the torque or current load, consider the type of operation. Will the generator run continuously for long periods of time, or in intermittent operation cycles, or during short intervals only? Accordingly, a motor size with sufficient continuous torque or current has to be chosen.

Also respect the maximum speed of the motor type. However, due to the generally low speeds this is hardly ever an issue.

#### Current and voltage limitations

The most appropriate winding of a given motor type follows from the current and generated voltage requirements. Select a winding that can generate the required voltage  $U$  even under load.

Assuming a fixed generator speed  $n$ , we require a generated voltage of the winding  $U_t$  that is larger than  $U$

$$U_t = \frac{n}{k_n} - R_{mot} \cdot I_L > U$$

Without considering the load, select the speed constant according to Rule #2, i.e. a winding with a sufficiently high resistance. Since the current capacity decreases with increasing resistance, verify that the continuous current is still large enough.

The chart quite nicely shows the ambivalent effects of different windings.

- The higher the winding resistance, the higher the generated (no-load) voltage.
- However, the higher the winding resistance, the more sensitive the generated voltage becomes to load current changes.

These contradictory effects can be eliminated to a certain extent by selecting larger motors that exhibit lower resistances for the same generator constant (according to Rule #3).

### Gear-motor combinations

#### Rule #4

Use gearheads to increase very low speeds. However, maxon gearheads are not really good at being driven from the output. Use gearheads that can be back-driven, i.e. planetary gearheads up to two stages or spur gearheads. (Or use specially designed gearheads.)

The reason to use gear-motor combinations for generators is that the driving mechanism is very slow – e.g. a wind or water turbine, or even a manual drive. A few observations and recommendations:

- The gearheads need to be driven in reverse operation in these cases. However, maxon gearheads are not really designed for reverse operation, and the efficiency is low.
- High reduction gearheads (3 stages and higher) are not back-drivable; i.e. they won't turn when driven from the output with the maximum permissible torque. You may use 1 or 2 stage planetary gearheads; they can be operated from the output.
- Rather use spur gears instead of planetary gearheads. Spur gearheads can more easily be back-driven and the back-driving efficiency generally is higher.

### Special case: DC motor as DC tachometer

#### Rule #5

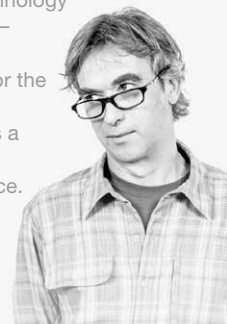
For DC tachometers, use DC motors with precious metal brushes that better suit the small currents. Select the winding according to the required tachometer voltage and the speed range in your application. Don't worry about the winding resistance, just make sure that there is a load resistance of several kΩ to keep currents small. REDACTED

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**Urs Kafader** has been supervising the technical training at maxon motor for more than 20 years. He runs training sessions on the technology and use of maxon products – for employees at the maxon headquarters in Sachseln, for the international sales network, and for customers. He holds a Ph.D. in physics as well as an MBA in production science. He began his career at the Laboratory for Solid State Physics at the Swiss Federal Institute of Technology, Zurich.



# Stepping it up a notch

Stairs are still unsurmountable obstacles for many robots. Yet a young team at ETH Zurich is building a vehicle designed to negotiate steps with ease – by hopping.



maxon EC frameless  
90 flat, brushless, 260 W

**A**scento is the name given to the sophisticated device by its creators, a team of eight students majoring in mechanical engineering and one in electrical engineering. The robot is quite special: It moves and balances on two wheels. From an engineering standpoint, this is significantly more difficult than building a device on four wheels. However, a bipedal robot provides much better mobility and adaptability to different terrain types.

That's not all: The main goal of the nine up-and-coming engineers is to make the robot leap. They want it to be able to jump high, like a kangaroo, and land again safely on its two wheels. "This would enable the robot to master stairs and other obstacles," student Florian Weber explains. The Ascento team originated from a focus project. In this type of project, undergraduate students of various disciplines have a chance to apply their knowledge to a

concrete project – from the initial idea to a functioning prototype.

The special feature of the Ascento is that it is designed as an inverted pendulum: The center of gravity is above the axis. As a result, the Ascento is able to stand and move only as long as it is powered and actively maintaining balance on its wheels – similar to a standing human, who continuously has to expend energy to maintain balance. This makes the Ascento comparable to a Segway, which is also driven by two wheels that are on the same axis and requires a controlled drive to maintain balance.

Potential applications for the Ascento are for example building inspections, as the vehicle could enter a house that's on fire or in danger of collapse. A built-in camera would deliver valuable information to rescuers outside the building. There are already various robots for these purposes. However: "Especially when it comes to climbing stairs, many robots reach the limit of their ability," says Marcus Vierneisel, who is also a member of the nine-person focus group. The goal for the Ascento is to enable it to climb stairs at a human's walking speed. Due to its lightweight two-wheeled design, the Ascento is more agile than other robots anyway. "On the other hand, larger robots are able to interact with their environment. This is something that Ascento cannot do," adds mechanical engineering student Lionel Gulich. Equipped with sensors, the Ascento would be able to scout a building and deliver 3D scans of the rooms in a short time. Of course, the prototype won't be able to scout a whole building by itself yet. However, it will be able to approach a flight of stairs on remote control and then use its sensors to measure and calculate the height and length of the jumps required to climb each step. "Triggering each jump via remote would be too complicated and slow," Florian Weber says. This puts the Ascento in the category of semi-autonomous robots.

It is still uncertain whether the focus project and the Ascento prototype will eventually become an inspection robot ready for commercial production. However, this is not the primary goal. Focus projects serve mainly to let ETH students try their hand at an actual project instead of just cramming theory.

The students are receiving technical and financial support from the drive specialist manufacturer maxon motor, as part of the

company's Young Engineers Program (YEP). The Ascento's drives include two maxon EC 90 flat motors. Technically, the torque of 963 mNm delivered by these motors is somewhat overdimensioned when the robot is moving along a single plane. However, the drives come into their own when balancing the Ascento after landing on a narrow step, as this requires high torque and precise control. The ETH students decided to use the frameless version of the motors. Rotor and stator are delivered separately and without an output shaft. The rotor and stator are connected only during the integration into a system. Especially in robotics, maxon frameless motors are often the first choice because they enable space-saving and elegant integration into joint structures. Each motor is driven by an EPOS4 module. ■■■

## Young Engineers Program

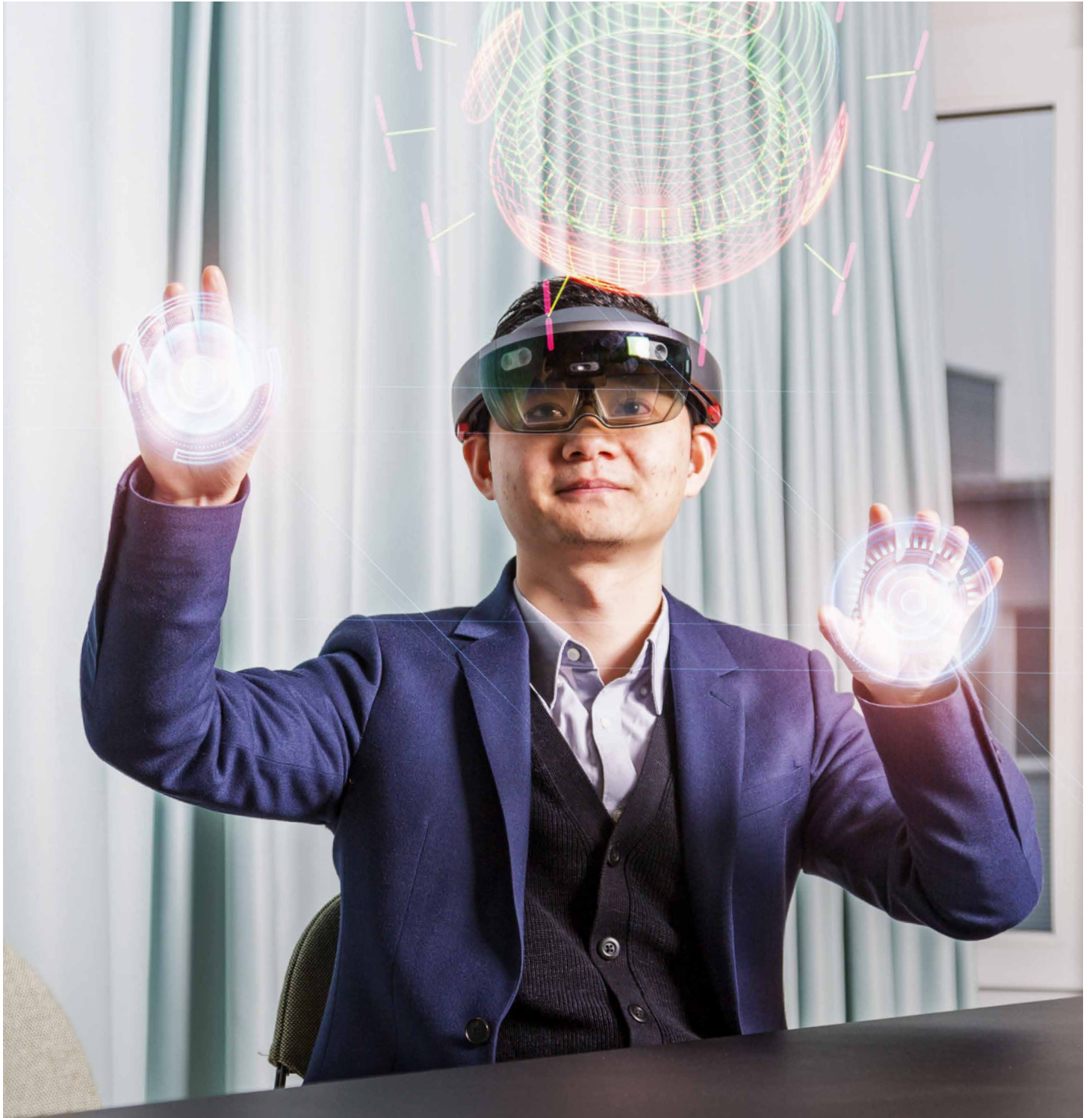
maxon motor's Young Engineers Program (YEP) supports innovative projects with discounted drive systems and technical advice.

Apply now:  
[www.drive.tech](http://www.drive.tech)



Students at ETH Zurich are building a robot with that certain something: the jumping Ascento.





# How customers benefit from **digital transformation**

Autor: Ning Liu

Photos: Jeremias Wieland / maxon motor ag

“How did you go bankrupt? Two ways. Gradually, then suddenly.” This line from “The Sun Also Rises” resonates in an economic environment where organizations, from agile young startups to established industry giants, are facing the challenge of digital disruption.

**S**tatistics show that the average life span of companies in the S&P 500 has declined from 61 years in 1958 to about 20 years now. At maxon motor, we are always asking ourselves: How can we be successful in this fast changing world? How can we provide more value to our customers?

### Change is everywhere

Industry boundaries are being redefined, access to assets is becoming more important than ownership, and linear value chains are becoming digitally connected ecosystems. This new environment requires companies to commit to a strategic digital transformation in order to survive. Digital transformation allows organizations to reinvent themselves – transforming the core of the business, finding and exploiting new sources of value.

A great example is General Electric’s “Digital Wind Farm”, which connects the embedded sensors and controls in the actual wind turbine, providing connectivity across multiple layers. The blades of the turbine are able to sense the environment. Using technologies such as radar and LIDAR, they know where the wind is coming from, and motors shift the pitch of the blade to react to the wind. So, the whole wind farm is orchestrating, communicating and optimizing for that specific environment, even for microclimates that may be different within the wind farm. The turbines are then able to send information about the cost and the quality of the energy being generated to the utility company. This way, the utility company can plan to not use other energy sources, such as coal or gas, when wind is more efficient. It’s all done with the help of cloud-based platforms, which provide a digital infrastructure for the wind farm, enabling collection, visualization and analysis of unit and site-level data.

### Digital transformation at maxon

How are we, maxon as a global organization, harnessing the potential of Digital Transformation? In fact, we are transforming every part of the entire value chain into digital, including digital marketing and sales activities to better understand and serve customers. Today, customers can already configure a unique drive system online, specific to their needs. We are also improving our digital production constantly to ensure best quality, flexibility, and on-time delivery. Last but not least, maxon works on smart products for predictive maintenance.

### How customers profit

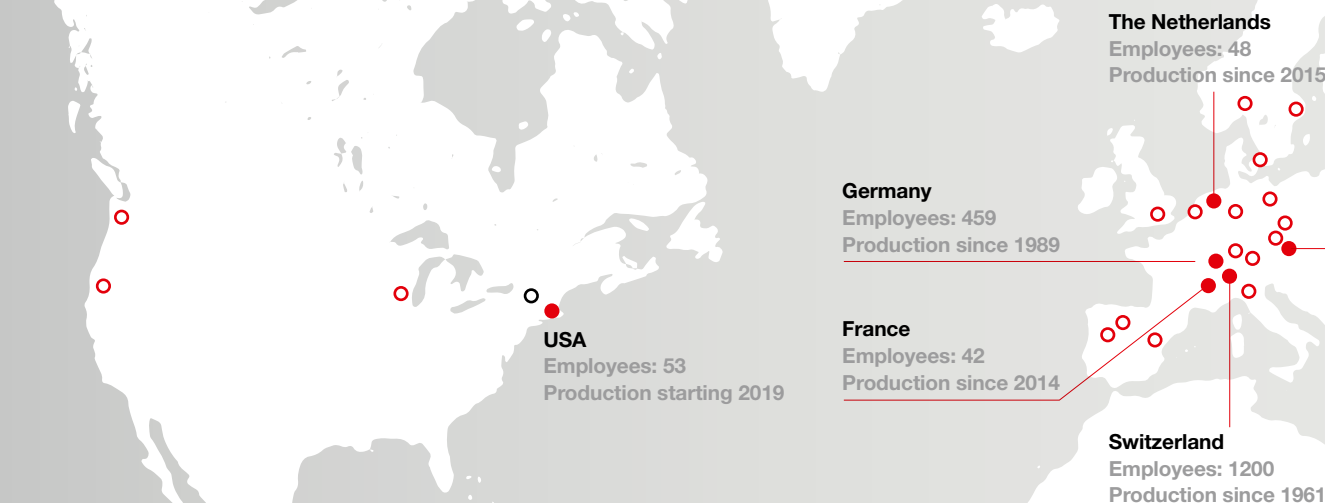
Robots “walk” into the factory and work hand-in-hand together with people. This is happening right now. We are adopting collaborative robots, such as YuMi from ABB robotics, into the production & assembly process to ensure zero-defect and on-time delivery of our products. At the same time, our smart motion control systems, embedded with IoT (Internet of Things) functionality, can automatically detect potential defects or lifetime warnings and send alerts to customers. But there is more to come. With the integration of artificial intelligence, e.g. computer-vision-based quality control, we are striving to provide the best quality to our customers, as always. ■

**Ning Liu** is Global Digital Manager at maxon motor. He has a master degree in artificial intelligence and robotics. Ning builds his interests and solid foundation in the technical field through advanced research within the areas of artificial intelligence, virtual reality & augmented reality. Ning completed his MBA at IMD in Lausanne and got to know Switzerland during this time. At maxon motor, he focuses on uncovering potential in the fields of digitization, including artificial intelligence, robotics, IoT, virtual reality, etc., across all divisions of the company.

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# Close to the customer

maxon motor is opening a new production facility in the US at the end of 2018. Here you can see where the drive specialist can be found around the world.



## PRODUCTION 2017

Motors:

**3.9 million units**

Controllers:

**834,000 units**



## SPECIAL MARKETS

Industrial automation  
Transportation  
Robotics und e-mobility  
Aerospace  
Medical





## Contest

In which country is maxon motor opening a new production site at the end of 2018?

The solution is somewhere in this magazine. Simply e-mail your answer to [driven@maxonmotor.com](mailto:driven@maxonmotor.com)

You can win one of three **Bionic Bird Deluxe Edition** drones. These drones can be controlled from a smartphone, have a range of 100 meters, and can reach speeds of up to 20 kilometers per hour.

Entries close on June 30, 2018.

Winners will be notified. Employees of maxon motor are not eligible to participate. There will not be any correspondence in regard to the contest. All decisions are final.



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## Ready for the Red Planet

This brushless EC 32 flat DC motor with a cogging torque brake has been specially optimized for NASA's next Mars mission. Nothing can shake it, neither strong impacts nor vibrations during the rocket launch. The motor withstands temperatures from  $-130$  to  $+115$  degrees. Its task: Handling the soil samples inside the Mars rover, in cooperation with other maxon drives.