

The maxon motor magazine

# driven



## Your friend and...

Robots in the home, in industry and for use in catastrophes

His name is Yochai



From 0 to 30 km/h in 3 seconds





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Photos: Flavia Schaub, Sphero, ARRI, Otto Bock, maxon motor/Philipp Schmidli, Universität Bielefeld, maxon motor ag, Aldebaran Robotics/Vincent Desailly, Alessandro della Bella

Editorial

# The robots' success is a success for us as well



Eugen Elmiger, CEO, maxon motor ag

I don't know about you, but I am astonished by the progress being made in robotics. Machines in industrial operations are becoming more precise and intelligent – they can provide direct assistance to people. At the same time, engineers are developing robots that can carry out tasks independently in catastrophe zones. And in Asia, Pepper is driving everybody crazy. I can well imagine that these social robots will soon be taking over in a lot of households. The demand is already enormous.

The success of Pepper is also a success for maxon. Right from the start we were involved in the development as a partner; we tested and adjusted until our motors fit perfectly into the system. So we at maxon are following with great interest how the story of Pepper and all the other robots unfolds. *driven* gives you an insight into this fascinating world of robotics.

Happy reading!



The current tablet edition with interactive and multimedia features can be found in the Apple App Store and now also on Google Play.



# The bionic supermodel

Rebekah Marine, 28, bionic model, took to the runway in September at the New York Fashion Week. Born without a right forearm, she refused to let it hold her back. She publicly appeals for more tolerance in the modeling industry for women who don't correspond to the norm. On the runway, Rebekah Marine wore her modern prosthetic i-limb quantum from British manufacturer Touch Bionics. DC motors and planetary gear-heads from maxon ensure perfect gripping movements with a diameter of 10 millimeters.



Photos: Rebekah Marine, Shell

## Shell Eco-marathon

### The battle for energy efficiency

It's early, the hall is filling up with the sounds of an exciting competition, people talking, tools falling, and occasionally an engine starting. People are running back and forth, there is panic in their eyes; the inspectors have a stern look on their faces as they carry out their inspections and the air is filled with the smell of exhaust fumes, rubber, sweat and coffee.

Welcome to the Ahoy in Rotterdam – the location of the 30th edition of the Shell Eco-marathon Europe 2015.

The teams are working hard to win one of the prizes. Naturally, the most energy-efficient car in its class and the off-the-track prizes are highly desired by the participants. Yet, there is no guarantee of success. Even the very best preparations say nothing about the result. You never know what you will encounter: a hole in

the road, a failing part, a sick team member...

That is also the appeal of the competition. After a year of preparation, from designing to actually constructing and testing the car, everything comes down to the actual race. Each year, student teams are challenged to push their limits. And each year, the rules are changed and tightened to ensure it does not become a routine task. After all, it is all about developing energy-efficient technology. Moreover, that has been proved highly effective: In 1985, the winner drove 680 kilometers with 1 liter of gasoline. 2015, the winner achieved a liter-to-kilometer rate of 1 : 2251.

Many of the teams in the Battery Electric and Hydrogen Fuel class drive with maxon motors, making maxon the proud partner of many winners! This year, maxon also supported a brand-new high school team in their first-time participation, resulting in 30 students having a once-in-a-lifetime experience. And hopefully they will come back next year when the Shell Eco-marathon takes place in London.

### 2015 at a glance



The first car built with 3D-printed molds on the Euregioregion (left).

The Green Team Twente Young from Bonhoeffer College were first-time participants (above).



## RoboThespian

**A robot as a clerk**

China – in the land of smiles, a young couple have been married by a humanoid robot. RoboThespian stands unobtrusively in the background of the wedding ceremony – he greets the couple with his computerized voice and begins his address. After the couple have said “I do,” he hands the rings to the bride and groom. The “clerk” is a humanoid machine who can dance, sing, present and act – but that’s not all. The robot even imitates emotions. He certainly faked a digital tear or two during the wedding.

The British company Engineered Arts has developed the life-sized robot in such a way that his movements are very similar to a human’s. These movements

are made possible by an intelligent combination of “muscles” powered by compressed air and maxon motors. In the hands, arms and torso of the robot, a mix-ture of A-max high-performance motors and RE-max motors with neodymium magnets and planetary gearheads from maxon are used. According to Engineered Arts Managing Director Will Jackson, RoboThespian’s movements must be as quiet and precise as possible when showing or explaining something to visitors to exhibitions. At the same time, he must be able to deal with long working hours. “maxon DC motors are ideal for this difficult combination of requirements. They deliver absolute precision and are extremely reliable.”

Look up the wedding ceremony: [youtube.com > RoboThespian wedding](https://www.youtube.com/watch?v=RoboThespian_wedding)

**46 km/h**

**Speed record.** The Raptor walking robot, developed by researchers at the Korea Advanced Institute of Science and Technology (KAIST) can run at up to 46 km/h. He is therefore the fastest two-legged walking robot in the world. The robot design was based on the model of a velociraptor dinosaur. Raptor is just under 50 centimeters in height and weighs just 3 kilograms. He can balance himself and jump over obstacles of up to 10 centimeters in height with ease. Each leg of the robot is driven by a brushless maxon motor. The drive systems consist of a high-performance EC-4pole 30, combined with a planetary gearhead GP 32 HP and an MR encoder. The controller consists of a maxon ESCO module 50/5. The robot was developed by Prof. SooHyun Kim, Prof. KyungSoo Kim, Prof. Daigil Lee, Dr. JongWon Park, Jinyi Lee and Jinwoo Lee.

Photos: Engineered Arts, KAIST, maxon motor ag

## NEW PRODUCTS



EPOS4 modules 50/15 and 50/8

EPOS4 modules 50/15 and 50/8

**Concentrated motion control power**

With EPOS4, maxon motors is launching the next generation of the successful EPOS product range. The proven concept of the CANopen position controllers will now feature new functionality and improved control performance. A modular expansion project will also enable connection to various fieldbus interfaces and feedback providers.

The first product in the range will be the high-performance EPOS4 module with detachable pin headers in two power variants. Both modules have a particularly impressive power density: up to 1,500-watt peak power at dimensions of just 57 x 62 millimeters. They are suitable for both the control of brushed and brushless DC motors.

Industry 4.0 at maxon

**Online configurator with new brushless DC motors**

Simply configure online and place your order. With maxon motor’s configurator, it is easy to put together a tailor-made DC motor. This is now also possible for three brushless models. And these motors thrive on speed.

Full connection doesn’t only take place in private. It has also seized industry. Here, the interlinking of development, storage systems, machinery and tools is termed industry 4.0. Manufacturing processes are becoming more flexible. The customer is benefiting from tailored products that they can configure themselves – and from a short delivery time.

maxon has already been offering this system for three years. With the aid of the online configurator, customers can put together their DC motors exactly as they wish. They select the right winding, flange, shaft and much more. The result is forwarded to maxon and integrated into the semi-automatic production process in Switzerland. After a maximum of 11 working days, the finished drives leave the factory.

maxon has constantly expanded the range of motors, gears and encoders in the configurator, so that today, drives with a diameter of 10 to 35 millimeters are available. And now, finally, brushless DC motors will also be added: models ECX 8, ECX Speed 16 and ECX Speed 19 will be added to the line with immediate effect.

These drives can be sterilized and reach very high speeds of up to 120,000 revolutions per minute. They produce hardly any noise and very little heat. They are therefore the ideal drives for applications in the medical sector.

Online configurator:  
[ecx.maxonmotor.ch](http://ecx.maxonmotor.ch)



maxon ECX Speed 16  
Ø 16 mm, brushless



maxon ECX Speed 19  
Ø 19 mm, brushless



# Friend. Machine. Rescuer.

The number of robots being used on factory floors and in households is constantly growing. And they are solving increasingly complex tasks. Machines like the Terminator remain a fantasy for the future. But one thing is for sure: There will be much closer interaction between robots and humans in the years to come.

**T**hey are everywhere. They mow the lawn, they milk the cows, and they assemble our cars. They teach children, and motivate residents of nursing homes to do their daily workout. Robots are on the march. And their numbers are growing.

Last year, industrial companies bought over 200,000 robots worldwide – more than ever before. In two years, the numbers will double, mainly because of the high demand from China. Service robots are also becoming increasingly popular. According to estimates, their market potential could reach USD 20 billion by 2020. Robots have been around for decades, but now the technologies appear to be ready for a real breakthrough. Maybe these machines really represent the fourth industrial revolution, after the car, the computer, and the smartphone.

Photo: maxon motor ag / Daniel Gillet



## The family member

Robots learn to recognize and react to human emotions.

Magali Cubier is certain that this revolution is going to happen. She is the global marketing director at Aldebaran, a French robotics company, and she is currently a very busy woman. The whole world is talking about Pepper, Aldebaran's robotic prodigy. He is 120 centimeters tall, slim, moves about on

three wheels and has humanoid features like a head, torso, and arms. With his big round eyes, Pepper looks cute. He is designed to be a companion and entertainer. How does that work? He is able to read emotions and respond accordingly. When the person opposite the robot hangs their head or slumps their shoulders, Pepper tries to brighten the mood by telling a joke, dancing or playing some music. Cubier says: "Our robots should help people and accompany them in their daily life." Pepper is equipped with several sensors and cameras, as well as highly complex software that enables him to learn. Given time, he will know how to associate voices and faces with different people and be familiar with the preferences of his users. If you ask him about the weather, he responds with the current forecast. He can access upgrades over the Internet.

In this manner, Pepper will acquire more and more capabilities. Customers seem to like the idea: In June 2015, Aldebaran's parent company SoftBank sold the first 1,000 Pepper robots within one minute. Significantly greater numbers will be available soon. The potential uses are almost endless: Families buy it for entertainment. For dementia patients, the robot serves as a butler who wakes them up, reminds them to take their medicine, or plays memory games with them. Already, Pepper greets customers in Japanese phone shops. Like everywhere in Asia, there is a veritable robot craze going on in Japan. Time will tell whether Pepper will also make it in the less robotophile European countries. Magali Cubier comments: "Some people are a little bit shy when they meet our robots. That's why we

programmed Pepper to approach people and talk to them. When they realize how easy it is to interact with the robot, they relax and begin to have fun."

### Romeo automatically calls emergency services

Pepper will always remain just a communication robot – unlike his bigger brother Romeo. Romeo walks on two legs, is taller than Pepper at 140 centimeters, and is equipped with powerful arms. He will be able to carry two full bottles of water, to climb stairs, and open doors. In the future he will also communicate with his users and read their gestures and emotions. Romeo will be a perfect assistant to the elderly. He will immediately respond when something is wrong and automatically call emergency services. However, Romeo will never be a mass-market product. The robot is one of Aldebaran's research projects and can only be found in a few European laboratories. These laboratories are working to improve Romeo's walking ability, navigation, and human-robot interaction. "We want to benefit from the research and build future products based on the insights gained," says Rodolphe Gelin, head of development at Aldebaran. Romeo is the prototype for future nursing robots. Considering that the global population continues to age and professional care service providers are becoming scarce, there will be great demand for such robots in the future.



Download tablet issue  
2 // 2015 to see how Pepper  
dances in the video.  
[magazin.maxonmotor.ch](http://magazin.maxonmotor.ch)

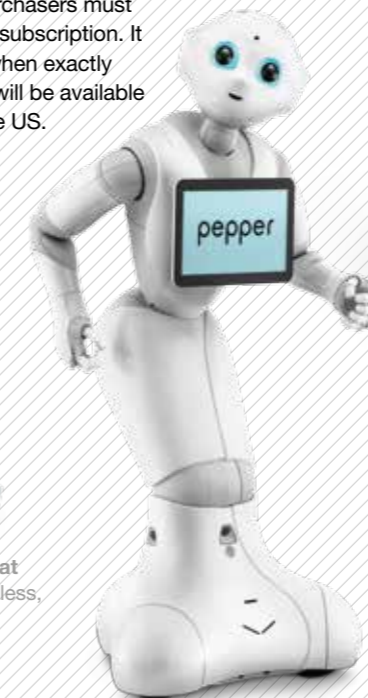
### Pepper – Aldebaran

Size: 120 cm  
Weight: 28 kg  
Motors: 6 maxon motors

Pepper is the flagship product of the French robotics company Aldebaran. He can read and categorize facial expressions, gestures, and emotions, and respond accordingly. The robot moves on three wheels installed in its base. The wheels are driven by two brushless flat motors by maxon, the 70 W EC 45 motors. These deliver high torque and are renowned for their long service life. For the time being, Pepper is available only in Japan for a price of about USD 2,000. Purchasers must also take out a subscription. It isn't clear yet when exactly the cute robot will be available in Europe or the US.



maxon EC 45 flat  
Ø 45 mm, brushless,  
70 W



maxon RE 40  
Ø 40 mm, graphite brushes,  
150 W

### Romeo – Aldebaran

Size: 146 cm  
Weight: 37 kg  
Motors: 37 maxon motors

Romeo, the robotic assistant by Aldebaran, is equipped with 37 maxon DC motors. The brushed DC motors come with the ironless maxon winding. This ensures excellent control behavior. Moreover, current is proportional to torque. This means that the controller can use current measurements to determine when Romeo has reached or collided with an obstacle. "This force-feedback makes the robot safer," says Rodolphe Gelin, director of the laboratory for artificial intelligence at Aldebaran. Gelin and his team have been relying on maxon motors for years. Motors by maxon are installed in all three Aldebaran robots: Romeo, Pepper, and the smallest model, Nao.



Romeo is the prototype for future nursing robots.



## The assistant

Factories are another place where there is increasingly close interaction between humans and robots. “Get out of the cage!” is the order of the day. Numerous manufacturers are offering lightweight models that work hand in hand with people on the factory floor. This new generation of collaborative robots is smaller than previous machines, which are often used in the automotive industry and operate behind large protective barriers. Because the new devices are placed close to people, they must not be too fast or too strong. Safety comes first.

While these robots do not have to read any emotions, they still need to detect what is going on around them. This is achieved with sensors and cameras. When a person comes too close, the robot immediately stops moving. Many manufacturers also use soft materials. The Swiss start-up company F&P Robotics, for example, sheathes its robotic arms in two-tone artificial leather. On the inside, the robots are equipped with brushless DC motors by maxon – one drive for each joint. The design objective is the same as everywhere in robotics: maximum power, as compact as possible. This is because higher-torque motors need smaller gearboxes, or even no gearbox at all. This saves space and money.

### Learning through interaction

Since we just mentioned cost: The more affordable collaborative robots are targeted towards small and medium-sized businesses. These businesses are coming under pressure to automate their processes, if they want to survive in the market. They need machines that are easy to operate and to program. Virtually all vendors, from ABB to Fanuc and Kuka, have introduced teaching processes. This means that a user grips the robotic arm and moves it into the desired position. The robot memorizes the position and performs the movement autonomously afterwards.

This is only the beginning, and yet: Collaborative robots have already changed the

manufacturing processes for small parts, in electronics assembly workshops as well as in laboratory automation. Hansruedi Früh, CEO of F&P Robotics, is convinced: “Our robotic arm, P-Rob, can handle vessels and tools or work in quality control.” When controlled with state-of-the-art software, it is able to recognize, grip, and manipulate objects – always in collaboration with a human employee. These machines will soon be intelligent enough to analyze and correct errors in the production line autonomously. This will naturally result in a reduction of the workforce, at least in some assembly processes. Robotics companies, on the other hand, will grow – if they play their cards right.

**Industrial robots stop moving as soon as people come close to them.**

Robots continue to develop through collaboration with humans and will soon be able to independently analyze and rectify errors on the production line.



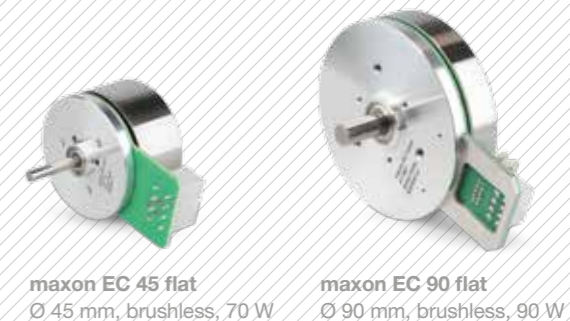
Photos: F&P Robotics, maxon motor ag



### P-Rob – F&P Robotics

Size: 100 cm  
Weight: 16 kg  
Motors: 8 maxon motors

This robot arm has a skeleton consisting of aluminum and an outer shell made from artificial leather. It is equipped with six degrees of freedom. Each joint contains a brushless DC motor from maxon. These are flat motors with diameters of 45 and 90 millimeters and power of 70 or 90 watts. “We think that the flat design in particular is a great advantage,” says Hansruedi Früh, CEO of F&P Robotics. He and his team are already launching the successor to the robot arm in autumn 2015: the P-Rob2, which is even slimmer in design.



maxon EC 45 flat  
Ø 45 mm, brushless, 70 W

maxon EC 90 flat  
Ø 90 mm, brushless, 90 W



## The lifesaver

But there are some situations where we wouldn't mind being replaced by a robot. Take Fukushima, for example: The nuclear disaster would have been less severe if there had been somebody inside to open certain valves right after the incident. However, the radiation would have been lethal to humans, and robots were not sufficiently developed yet for such a task. This is about to change.

This summer, 23 teams from five countries participated in the Darpa Robotics Challenge (DRC) in the US. The engineers used robots to solve a variety of problems, all of which were realistic scenarios that might occur after a catastrophic incident. The robots had to drive cars, cut holes into walls, open doors, operate valves, and negotiate difficult terrain. It became clear that we are not going to see a Terminator machine like the one in the movies anytime soon. In particu-

lar, the task of walking on two legs like a human remains a big challenge for robots. Most models kept falling over and were somewhat

reminiscent of drunks. The winning team from South Korea used a trick: Their robot DRC-Hubo has two legs, but it can also move on rollers mounted at the knees. This hybrid solution turned out to be extremely efficient. DRC-Hubo had the necessary stability and solved all tasks in the shortest time. The team from the KAIST institute won the USD 2 million prize money.

### High demands

For their robot's primary joints, the Korean engineers used 33 maxon DC motors, mainly consisting of brushless EC-4pole drives. These drives have a very high power density and can be operated in overload. The KAIST team maximized the use of this option by installing an air cooling system for even more power. "We have a long working relationship

with maxon and a great deal of experience with their motors. We have full confidence in their high quality and performance," says Professor JunHo Oh, the team's leader. At the competition, he explained that Hubo is nothing special, "just a humanoid robot." This seems like quite an understatement if you look at what Hubo has achieved. The Koreans have built five exemplars so far, each with an estimated value of between USD 0.5 and 1 million.

The engineers behind DRC-Hubo report that their robot is already able to perform simple missions and reconnaissance. In ten years, it is thought that robots will be advanced enough to perform complex tasks in hazardous environments. What is still needed to achieve this? Robots will have to learn to overcome unexpected challenges autonomously. And then there is the problem of walking upright, which the developers at Hubo are also trying to solve. They want their robot to remain safe and stable when walking in uneven terrain, just like a human – or at least, almost. ■■■



At the Darpa Robotics Challenge, catastrophe robots had to prove themselves in many disciplines, including driving a car, operating valves and negotiating difficult terrain.

Photos: KAIST, Darpa

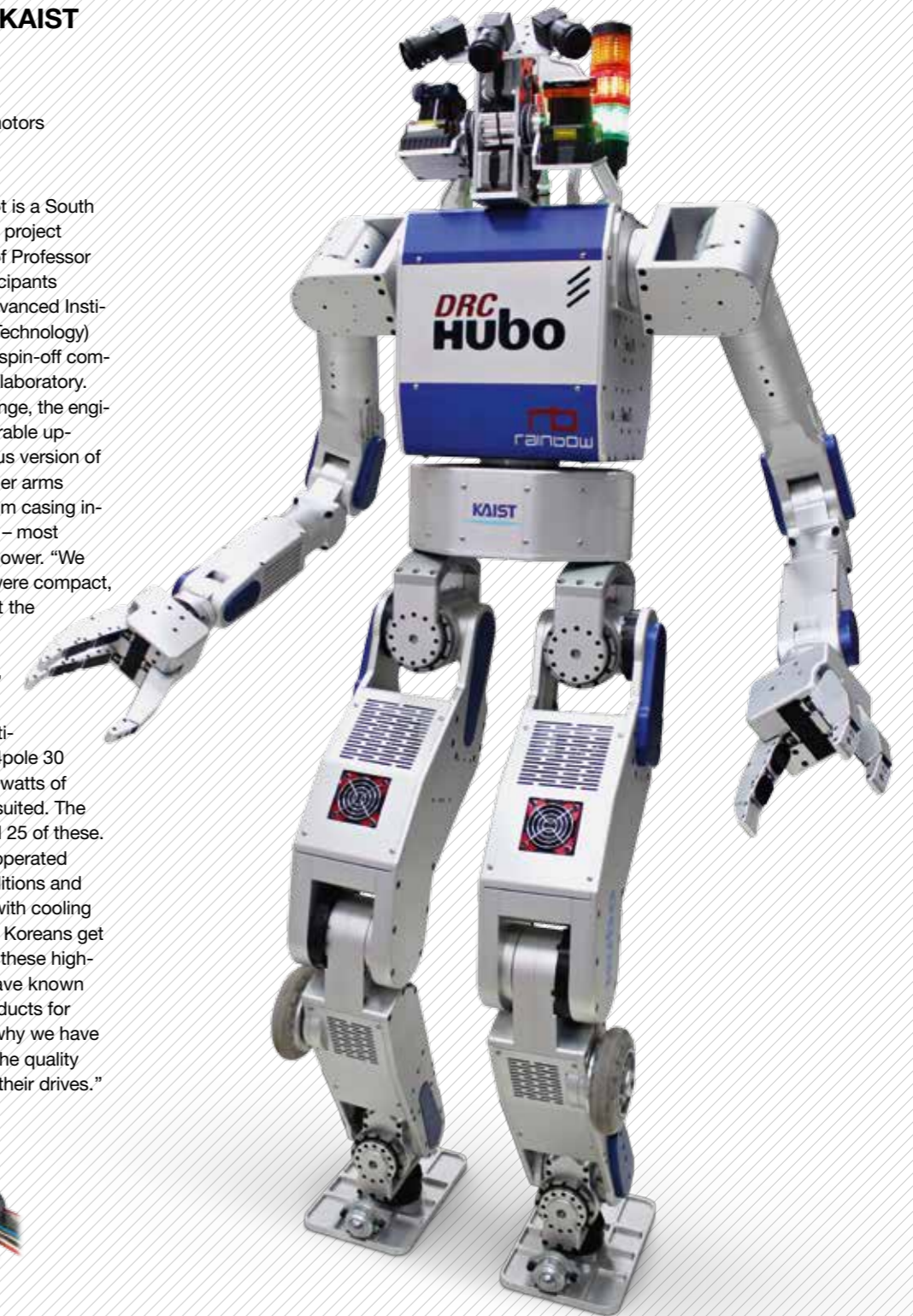
## DRC-Hubo – KAIST

Size: 180 cm  
Weight: 80 kg  
Motors: 33 maxon motors

The DRC-Hubo robot is a South Korean collaborative project under the direction of Professor JunHo Oh. The participants are KAIST (Korea Advanced Institute of Science and Technology) and Rainbow Co., a spin-off company from the Hubo laboratory. For the Darpa Challenge, the engineers made considerable upgrades to the previous version of the robot. It has longer arms and legs, an aluminum casing instead of plastic, and – most importantly – more power. "We needed drives that were compact, light, and powerful at the same time. maxon motors fulfill all of these requirements," says Professor Oh. In particular, the multipole, brushless EC-4pole 30 DC motors with 200 watts of power are perfectly suited. The KAIST team installed 25 of these. They are frequently operated under overload conditions and therefore equipped with cooling fans. This is how the Koreans get the maximum out of these high-tech motors. "We have known maxon and their products for a long time. That is why we have great confidence in the quality and performance of their drives."



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







## His name is Yochai

Kate Darling – an American raised in Basel, a lawyer and robot ethicist at American technology hotbed, MIT. She conducts research at the institute's Media Lab into why people create emotional attachments to robots and how we will interact with our new friends in the future.

Photos: Flavia Schaub

**Kate, how did you come to be researching in the field of robotics? Has the topic always been one that interested you?**

Even as a child, I found robots very exciting. I studied law in Switzerland and initially accepted a legal position at MIT while doing my doctorate in 2011. In the last four years I have expanded my disciplinary horizons, so to speak, and now I'm increasingly studying robotics, psychology, and ethics.

**You have been researching in the field of robot ethics for the past few years, what does a typical working day in the MIT Media Lab look like?**

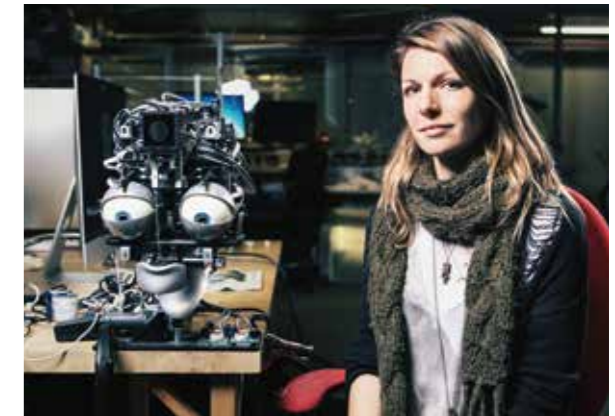
I don't really have a typical working day, every day is different! At the moment I'm working on several projects. That could mean: meetings with colleagues, getting up early to carry out experiments, spending all night analyzing data or working on a paper or traveling to a conference. Unfortunately what I spend most time on is probably e-mail.

**Pepper is a robot who reads emotions and can react to them. If you hang your head in front of Pepper, the robot tells a joke, dances or plays some music. This must lead you to create an almost emotional connection. Why do we anthropomorphize robots so much?**

We have a general tendency to humanize animals and even non-living things. Social robots play with this tendency and attempt by means of movement, design and programming to amplify these sometimes unconscious projections.

**How is an emotional bond to a robot created – a machine consisting of nothing other than metal, plastic and electronics and fed with clever algorithms?**

People are already capable of creating emotional connections to objects, such as cars or stuffed animals, for example. However, robots simply fall into another, more intensive category of these objects. We react strongly to the physical movement of the robot. If they are equipped with either characteristics or body parts that are typical of life forms, such as eyes for example, some people are quick to treat the robots like animals in certain situations.



Robot ethicist Kate Darling believes that we will perceive and treat robots like pets in the future.

**Does it not heavily depend on the appearance of a robot whether you develop feelings?**

Yes, appearance plays a big part. We even treat different animals differently depending on their external appearance. And people!

**What about armed military robots? Are they a danger to humanity?**

Like every other technology, it depends on how it's used. We should certainly be considering the possibility of autonomous weapons systems. What worries me the most is the distance between decision makers and the consequences of their actions.

**What might happen in the area of human-robot relationships in the near future?**

I don't believe that robots will replace interpersonal relationships in the near future. But I can well imagine that over time we will perceive certain robots in the same way as pets, and treat them accordingly.

**And finally: Do you have a robot at home yourself?**

Yes, a few! My favorite robots are my two Pleo dinosaurs, one is called Yochai and the other is Peter. Then there is a solar robot I built myself that walks around in an aquarium. His name is Herbert. ■■■

**Kate Darling (33)** was born in America and moved to Switzerland at the age of nine. She grew up in Basel. She completed her law degree in the same city. Kate Darling did her PhD at ETH Zurich. Since 2011 she has worked and carried out research at the Massachusetts Institute of Technology MIT Media Lab. Robot ethics is her area of research – she is particularly interested in the development by humans of emotional connections to robots, and how these “social feelings” for machines will affect humans in the future. When not traveling around the world attending science conferences, she lectures in robot rights and intellectual property on the Internet at the elite universities of Yale, Harvard and Cambridge.



# Playing with water

maxon motor is renowned for its high-quality precision drive components. But customers often want more. A look at Germany, where maxon engineers work on complex complete solutions for gigantic water shows.

The water fountains shoot up to 40 meters into the sky, drawing beautiful images, criss-crossing or forming parallel lines that harmonically swivel from side to side. Such water shows with dozens of fountains can be found all over the world: in the US, in Abu Dhabi, in China. Stationary or transportable. What they all have in common are high precision and attention to detail.

maxon is also about to dive into this waterworld. At the production site in Sexau, Germany, the engineers are developing an electrically controlled jet – lighter and more accurate than customary models. This is an unusual task for maxon. After all, as drive specialist, maxon is renowned worldwide for high-precision motors, gearheads, encoders and controllers. Yet in this case, maxon

is delivering entire installation units of these water jets to the German customer LKE Lasershowtechnik GmbH. In Sexau, everything comes together: engineering, manufacturing and assembly. “We have all the necessary expertise to offer such a complete solution in-house,” says designer Matthias Mamier. This is of advantage to the customer as it involves only a single contact partner who quickly implements his wishes and suggestions.

## Motors completely immersed in oil

The short communication channels are beneficial when it comes to an application with high requirements. This also applies to the water jet. An example: All parts have to be made of stainless steel, so that they do not rust under water. Salty sea water must also not affect the unit.



Photo: iStock/ralo





At the maxon factory in Sexau, entire installation units for water jets are manufactured.

### 1.7 million gearheads annually

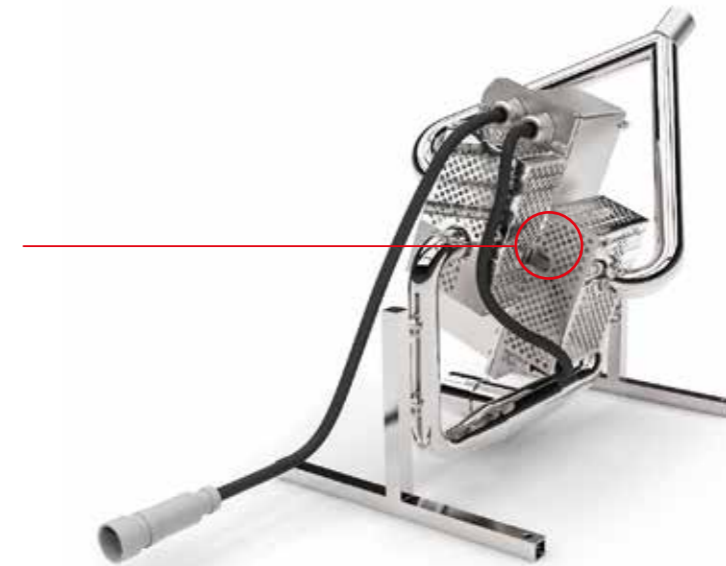
The maxon production facility in Sexau (Germany) was established in 1989. A large part of the factory has been completely rebuilt in 2014. Around 400 employees work in Sexau – mainly in the engineering and production of gearheads and special drive solutions. The center for ceramics, where different components such as cogwheels, spindles or head-phone housings are manufactured, is also located there.

In Sexau, maxon annually produces 1.7 million precision gearheads, with diameters of 4 to 52 millimeters. In addition to the headquarters in Sachseln (Switzerland), there are two other production sites, one in Hungary and one in South Korea.

Photos: maxon motor ag



**EC 45 flat DC motors**  
The motors in the water jet are brushless EC 45 flat DC motors, which can supply 70 watts of power. They are energy-efficient and have a high torque. The flat motors are each combined with a GP 42 planetary gearhead. It has three stages and has been slightly modified.



The conditions under which water jets are used put high demands on the material as well as the mounting and cooling of the motor-gearhead unit.

On the first floor at maxon, the mechanics machine the high-quality metal on CNC mills with micromillimeter precision. Here they create the cross manifold block, the heart of the water jet, so to speak. This work is no child's play, as employee Lothar Scheerer tells us. "The high percentage of chromium in the metal requires a certain amount of experience with machining it."

The entire motion apparatus of the water jets is also quite sophisticated. It consists of two axles that are each moved by a motor-gearhead unit – completely immersed in oil. This makes it possible to operate the drives in overload, as the fluid has a cooling effect. However, the oil must not leak out. Although it is biodegradable, it would discolor the water.

The drive itself consists of a brushless DC motor and a three-stage GP 42 planetary gearhead. The gearhead only has to travel a short distance. After all, maxon builds gearheads of all types in Sexau, from standard to special custom models (see box).

### Electrical controller offers many advantages

For the past two years, maxon Sexau has been working on the development of the water jet, which will soon be launched on the market. With the third generation of this product, the engineers have eliminated the last teething troubles: A new controller is able to com-

pensate for an uneven position. This is useful when the jet is standing on the bottom of a lake. The seals of the oil-immersed drives have also been improved, plus the entire unit is now easier to assemble. Markus Diringer, who has assembled all prototypes hitherto, is particularly happy about this last benefit. "The water jets weigh 19 kilograms, so any simplification of the assembly procedure is very welcome," he says, laughing.

Actually the low weight is one of the big advantages of the electrically controlled water jets. Hydraulic models weigh around 80 to 90 kilograms each. They also need large, loud oil units. Electronic water jets make such units superfluous. And they offer more flexibility.

LKE wants to conquer the water show market with these advantages – and has found the right partner in maxon. A partner that is more than just a drive specialist. ■



Download tablet issue 2 // 2015 and see how the water jets will be used in front of the Sheikh Zayed Grand Mosque in Abu Dhabi. [magazin.maxonmotor.ch](http://magazin.maxonmotor.ch)





# From 0 to 30 km/h in 3 seconds

The mountain biker speeds up the steep trail in the Swiss Alps. Higher and higher. Completely relaxed. His rear wheel is equipped with a powerful electric drive from maxon that gives him an extra push.

maxon engineers with the development of the Bikedrive by contributing his expertise.

**P**erfect for extreme trails, a tour around the lake with the kids in a bike trailer, or simply for a trip around the corner. E-bikes have become a common sight in everyday life and for leisure activities. The market is booming. The range of e-bikes available is huge. But a really compact, yet powerful e-bike motor was still missing. Up till now.

## “Now driving uphill is fun”

In May 2015, maxon motor officially presented the new electric drive for bicycles. The maxon Bikedrive is a hub motor that is installed in the rear hub of a bicycle. Together with a battery and PowerGrip (throttle grip), a normal bicycle can be turned into a speedy e-bike. White LEDs show the battery level, and a simple lamp indicates the motor temperature. The hub motor goes from 0 to 30 km/h in only 3 seconds. Such acceleration and power are highly exciting. “On the downhill trails, I still achieve the speeds that I clocked during my best times as racer. Now driving uphill is also fun,” raves Albert Iten, former downhill world champion from Switzerland. He assisted the

## How it all began

The idea for the e-bike drive was born in 2009, when Albert Iten and his good friend Roli Abächerli contacted maxon on their search for a powerful bike motor. As chance would have it, a former racing buddy was working for the drive specialist. And thus, pro cyclists sat down with engineers. The inventive minds at maxon quickly found a solution: A wind turbine from another project appeared to have promising characteristics for building an e-bike drive. With its ironless winding, the motor achieves an efficiency of up to 90 percent. This is not only good news for the battery consumption, but also for the energy recovery.

Applied research on the bike drive started in 2010. “The largest challenge was to manufacture a powerful motor that is simultaneously small and very easy to integrate. In other words, a compact motor with integrated electronics, sensors, gearhead, cabling – components that have to be perfectly matched to each other,” explains Benedict Keller, head of production for the Bikedrive.

2012, maxon’s CEO Eugen Elmiger became



Albert Iten, former downhill world champion, helped the maxon engineers to develop the Bikedrive.



See the image gallery for the Bikedrive in tablet issue 2 // 2015. You can also find more information in the Bikedrive blog: [maxonbikedrive.com](http://maxonbikedrive.com)



head of the project. “When I saw the compact design and technical sophistication of the first prototype, I immediately knew we would have to introduce this motor to the market,” Elmiger recollects. As a cycling enthusiast, he was very much aware of the flaws of existing drives: low efficiency, not enough power, and sub-par reliability. There was room for improvement.

#### From applied research to pilot series

The goal was to sell a complete system, in other words, motor, battery and, very importantly, the throttle grip, which is essentially the control center of the dynamic system. In total, 15 of the first prototypes were produced. In a second series, 30 motors – this time completely sealed – were produced and thoroughly tested. Seeing as the factory site is right next to the Swiss mountains, this is no problem. Jump slopes, mud and rain were welcome for revealing the weaknesses. Getting all components waterproof was particularly challenging. All in all, it only took two years from the first prototype to the pilot series.

#### The future is called “MARS”

The Bikedrive dealer network in Switzerland is continuously being expanded (see [maxonbikedrive.com](http://maxonbikedrive.com)). The logical next step is to found a separate business unit for mechatronic drive systems at the headquarters in Obwalden. MARS (Maxon Advanced Robotics & Systems) will develop and produce everything related to mechatronic drive systems, explains Heinz Schällibaum, MARS sales director. He and his colleagues focus on both continuous development of the Bikedrive and special robotic systems. The maxon Bikedrive is set to conquer Germany and Austria next year. Successively other countries will follow.

For the newest information, go to:  
[maxonbikedrive.com](http://maxonbikedrive.com)



#### Bikedrive – technical details

##### Motor

Weight: 3.5 kg (motor)  
Continuous torque: 25 to 30 Nm  
Max. torque: 50 Nm  
Efficiency: 85 percent

##### Battery

48 V lithium-ion battery with 360 Wh  
Weight: 2.8 kg  
Full power after two hours charging  
(70 percent after 60 minutes)  
Range: 1,000 to 1,400 m of elevation gain  
(depending on the weight of the cyclist)

##### Powergrip

3 stages + Turbo Boost  
Temperature monitoring with status LED





Elephants, lions or entire herds of antelopes – with a digital camera specially designed for documentaries, wild animals can be captured quickly. Motors made by maxon ensure that there are no chromatic aberrations in the recordings.

**maxon RE 8 motor**  
This drive delivers 0.5 watt of power, at a diameter of only 8 millimeters. It is equipped with precious metal brushes and the ironless maxon winding.



Photos: ARRI



The AMIRA sensor assembly with ND filter slider. One of the two RE 8 motors can be seen at the bottom right.

**35** degrees Celsius in the shade; the sun is burning hot. Not a single cloud in the steel-blue sky: That is the grassland savanna of Kenya, with its fascinating fauna and impressive landscapes. Documentary film teams from across the world are on the track of wild animals. A dangerous job; no one wants to get too close to lions, elephants and co. A jeep roars through the savanna on the search for the animals of East Africa. In the noon sun, a lion appears on the horizon. It is lying in the grass, almost invisible – and unfazed by the approaching jeep. The camera operator is ready. The ARRI AMIRA digital camera is ready to shoot. In a jiffy the king of the savanna has been captured – as an image. The temperatures put high demands on the team and the equipment. Gunter Föttinger, technical lead Embedded Image Processing at ARRI, explains that the camera contains a special cooling system, which has been designed to operate perfectly at temperatures of up to 50 degrees Celsius. Additionally each camera is subjected to a cold test at down to -20 degrees Celsius, which the video cameras can handle without problems.

**Filter change with maxon motors**

The motor-controlled ND filter (neutral density filter) installed in the ARRI AMIRA is moved in front of the sensor in situations with very bright outdoor light conditions. It reduces the intensity of the image in a “neutral” way. Neutral means that no chromatic aberrations are generated, instead, only the brightness is reduced. ND filters are important for achieving the desired look during the image capturing.

maxon RE 8 motors with MR encoder and GP 8 A planetary gearhead are used in this application. The brushed DC motors drive spindles in the sensor assembly that moves the filter into place in front of the image sensor and back again. ARRI chose maxon drives, as “it is the only 8-millimeter motor on the market that provides a sensible solution for a rotary pulse encoder with the same diameter,” says Michael Haubmann, hardware architect at ARRI.

**The digital camera provides an astonishing image quality.**

**Perfect for documentaries**

Animal documentaries are large productions made with as small a team as possible. The ARRI AMIRA has been specially designed for documentaries and single-operator use. The



# Controlling axes in robotics

Robotics is mechatronics in its purest form. Only the right balance between modularization and central coordination of the axes leads to success. Here you can learn what you have to keep in mind.



Photos: Otto Bock, maxon motor ag



**Urs Kafader** has been supervising the technical training at maxon motor for 19 years. He runs training sessions on the technology and use of maxon products, both for the employees at the maxon headquarters in Sachseln and for the international sales network, as well as for customers. He has a PhD in physics as well as an MBA in production science. He began his career at the Laboratory for Solid State Physics at ETH Zurich.

**H**ow do we find suitable drive components for robotics? Well, we use the same logic that we use in all other applications. However, in robotics, mechatronic aspects are of particular importance: actuators, sensors, mechanical systems and electronics – all combined with appropriate programming. There is usually a multi-axis system that has to be coordinated by the controller. The degree of coordination and synchronization depends on the specific task and the required dynamics. The right balance between modularization and central coordination of the axes is important.

## Motors and mechanical aspects

Arm or leg prosthetics are typical examples for mechatronic systems. The motors used can have completely different purposes: An individual motor may move a gripper, a finger, or an entire arm or leg. The motor on the shoulder joint needs to be relatively big and strong, yet the motors in the hand should be small and lightweight in order to reduce weight and mass inertia. The motor selection depends on the torque required and the dynamics of the application. The dynamics are not so much a question of the rotation speed, but rather of the acceleration capability, i.e. the ratio of torque to mass inertia.

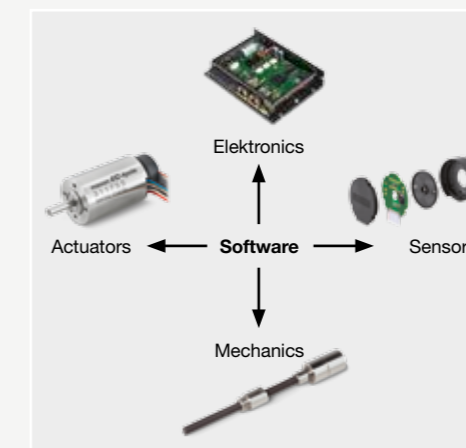
The mechanical system used has a large influence on the control. On the one hand, mechanical components contribute to mass iner-

tia, but they can also reduce load inertia to a “tolerable” amount for the motor. A reduction gear reduces the mass inertia by the square of the reduction. On the other hand, mechanical components exhibit play and elastic behavior. This makes it difficult to achieve stiff, precise control. Therefore direct drives tend to be chosen for high-precision, highly dynamic applications. These can be high-torque motors or real linear motors for translative load movements.

## Modularization

For drives, modularization means: Each motor is controlled locally by means of an intelligent controller. The central computer sends the motion commands via a fieldbus. This decentralized strategy provides high flexibility and has various advantages:

- The controller module can be adapted precisely to the power, configuration of the power stage and control parameters of a given motor type.
- The local cabling of motor and encoder means that no complicated shielding is required. Only the bus line and the power line have to be routed up to the respective module.
- Modularization makes it possible to use economically priced standard components. The development work is focused on the integration into the overall system.



Mechatronics as programmed interplay of mechanical components, electronics, actuators and sensors.

In the simplest case, several axes have to be adjusted independently of each other, for example on a gripper mounted on an x-y table. The gripper can grab an object or let go of it – independent of the current position. The movements in x- and y-direction at a certain position can be performed successively or simultaneously. In technical parlance this is called a loosely coupled system of axes that are receiving individual motion commands from the master system via a fieldbus. The movements are executed and controlled autonomously in the modules.

In the maxon product portfolio, the EPOS product family, operated in positioning mode, is an example of loosely coupled, decentralized modules. EPOS positioning motor



controllers are controlled via the CANopen fieldbus, which is affordable and compact, but at 1 Mbit/s, not particularly fast.

However, this controlling method has its limits. To accurately cut leather or film on an x-y table, much tighter coordination and synchronization between the axes are needed.

### Central control

For more complex applications, the axes are centrally coordinated. In delta robots, three motors are tightly coupled mechanically and their control functions have to be coordinated. Other examples for very precise and dynamic synchronization can be found in production systems, where “flying” machining is used to process parts.

In systems with tightly coupled axes, the positioning control loop is no longer closed locally in the module, but instead centrally in the master. The modules serve either as speed controllers or, for applications with extremely complex dynamics, in current controller mode. Each axis sends information about the motion status to the computer. The central path planning and control uses this information to generate motion commands for the next steps and sends these to the individual axes. Tightly coupled systems require a real-time bus system with adequate bandwidth. The computing capacities of the motion controller and master system also have to meet these requirements.

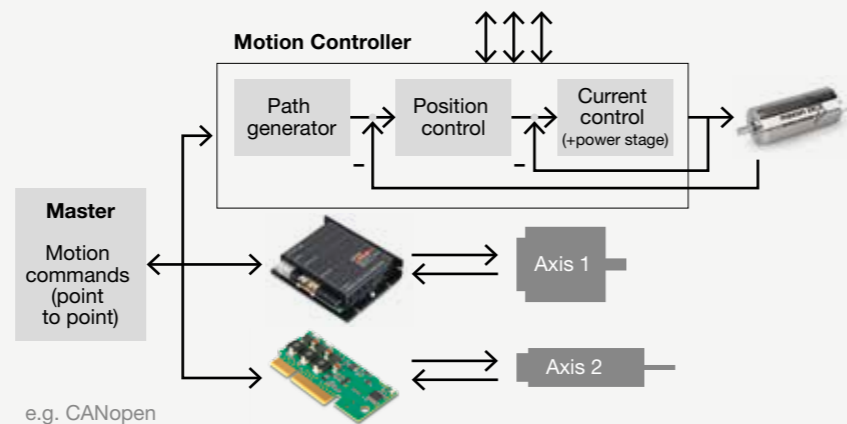
In the maxon portfolio, the MAXPOS is available for such highly dynamic applications. This EtherCAT slave motion controller receives motion and I/O commands from a higher-level EtherCAT master which carries out the process control. The extremely fast controllers, together with the diverse feedback options, provide ideal conditions for operation in high-performance applications.

### Feedback sensors

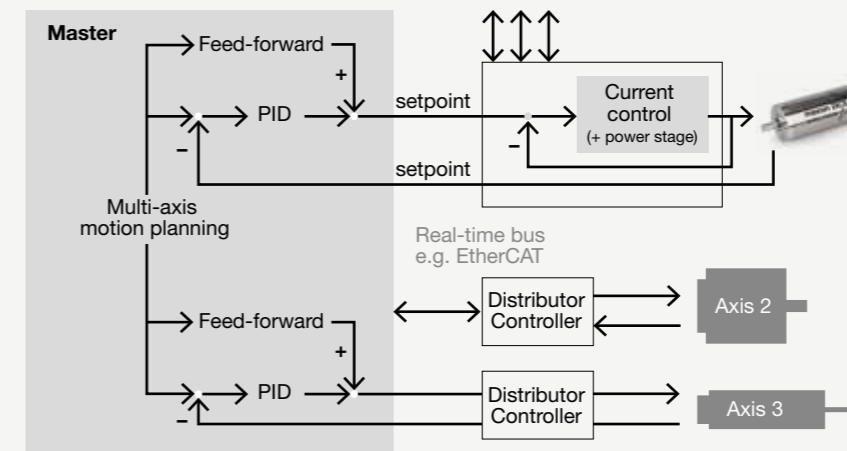
The standard sensors used in microdrives are digital or analog incremental encoders. They supply the position information rela-

tive to a reference position which first has to be determined during the start. However, in complex multi-axis systems, homing is frequently not desirable or not possible. Think of a robotic arm with several joints. In which order should the homing procedures for the individual joints be performed, without damaging the system, if the initial position of the arm is not known?

Absolute encoders detect the absolute position of the individual axes right at the start. They can be implemented fairly easily if the angular position only has to be coded during a single turn of the motor. Multi-turn encoders additionally require a mechanism for determining and storing the number of turns of the mo-



Basic structure of decentralized multi-axis coordination, with the benefits of short connection lines between controller and drive, power stages adapted to different motors, and networking via fieldbus. The path planning (path generator) and positioning are performed decentrally in the distributed controllers. The master only provides the target positions.



Basic structure of tightly synchronized axes. The decentralized controllers are configured as current controllers. The complete path planning for all axes, as well as the position control, is performed in realtime in the master. The controllers are connected to the master by means of a fieldbus with high bandwidth.

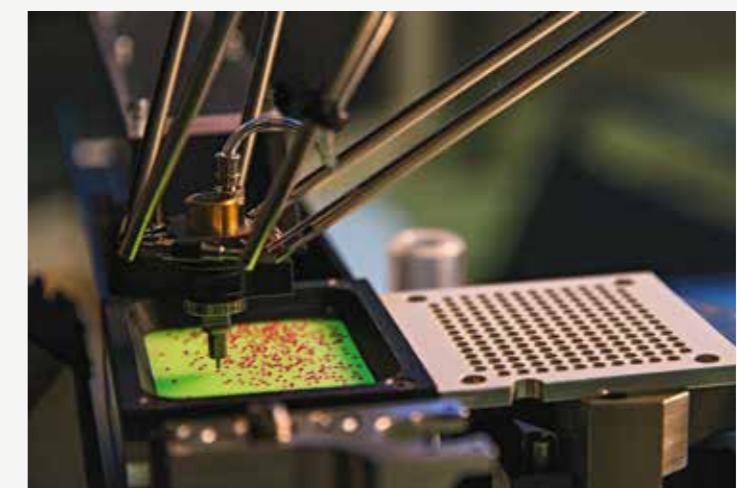
A natural fit for highly dynamic applications: the EtherCAT slave motion controller MAXPOS.



tor shaft, even when switched off, for example when the robot arm is repositioned manually.

### Conclusion

Robotics is mechatronics in its purest form. It can only be successful and economical if the right balance between integration and modularization is found. Integration results in the success of the total package, modularization allows the economical use of standard components. But don't forget: The quality of motion depends on the successful coordination of all the components involved – controllers, power elements, sensors, mechanisms, and load characteristics. There is no use in simply optimizing a single element. ■



Delta robots as example for tightly coupled axes.





Raffael Künzi gives the ETH team valuable tips for the development of the stair-climbing wheelchair.

Photo: Scalevo

# One wheelchair for all situations

Students of ETH Zurich have developed a wheelchair that can climb stairs. Is this the future means of transport for persons with walking disabilities?

**The Scalevo wheelchair has already been requested by people with walking disabilities all around the world.**

**T**est driver Raffael smiles. He is the first person with a walking disability that gets to drive up a flight of stairs with the Scalevo wheelchair – in reverse on two caterpillars. That is almost like floating. At the top, the journey continues on two wheels; the system is self-balancing. The wheelchair is a prototype of ETH Zurich and is currently not on the market yet – unfortunately. For many persons with walking disabilities, everyday life is filled with barriers. They usually have to circumvent curbs and stairs. Ten Swiss students want to change

that. In the future, no obstacle should prevent the freedom of movement of wheelchair users. The budding engineers developed a new type of wheelchair, within just a year. A masterpiece that took up practically every free minute

of the students' time. It was worth it. The first feedback received from persons with walking disabilities all over the world is positive "and many want to purchase our wheelchair already," says machine engineer Carlos Gomes.

#### It starts

Actually, Gomes and his colleagues only wanted to build a robot that can climb stairs. But their professor encouraged them to go a step further. That is how the eight engineers

of ETH Zurich started with the development of a stair-climbing wheelchair in the summer of 2014. It had to be very maneuverable, easy to operate – and, above all, safe. Additionally it should look good. The team recruited reinforcement: two industrial design students from the Zurich University of the Arts. And then they got started. The basic principle was found quickly. During normal operation, the wheelchair should drive on two wheels, like a Segway. They planned to overcome the stairs with caterpillars that can be extended and retracted. The wheelchair is called Scalevo and unites two motion principles in one: a hybrid chair, so to speak.

#### The practical test

Finally, this is what it looks like: The wheelchair user approaches stairs and selects the appropriate function on the touch screen. With sensors and cameras, the chair measures the incline of the stairs and automatically drives up to them in reverse. The caterpillars lower. They start to turn and move the wheelchair up the stairs. Speed: one step per second. The driver stays in a straight position the entire time. As soon as the sensors detect the end of the stairs, stabilizing wheels move into position. Thus the wheelchair cannot tilt over. Then the caterpillars lift up and the wheelchair continues the journey on two wheels.





maxon GP 52 C  
Ø 52 mm, ceramic version



EPOS2 70/10  
digital positioning motor controller

### Ceramic components for a longer service life

The drive of the Scalevo wheelchair consists of a brushless DC motor from maxon, with a diameter of 60 millimeters. It is connected with a GP 52 planetary gearhead which is specifically equipped with ceramic components. This modification gives the gearhead a significantly longer service life.

The maxon EPOS2 70/10 controller module ensures perfect control. It is a fast and precise digital positioning motor controller that is suitable for brushed and brushless DC motors.

The wheels and the caterpillars are equipped with two maxon electric motors that act as drives. Brushless DC motors are used in combination with ceramic gearheads. Ceramic is always a good choice when high forces act on the components, yet the gearhead has to be very durable. Carlos Gomes and his team are enthusiastic about the drives that maxon provided to them: “The motor-gearhead combination is strong, precise, quiet and, at 3.2 kilograms, relatively light. The maxon engineers gave us expert advice and the support was excellent.”

### The key to success

The students are very satisfied with their work. “Good teamwork was the key to our success,” says Gomes. Additionally, they implemented the suggestions of many persons with walking disabilities, like adding a belt or inclining the seat backward slightly, so that the wheelchair user does not slip forward. “We would never have thought of such details ourselves.”

### Time to face the competition

It is not the end yet. Even though the project could be considered finished. In 2016, the engineers want to compete in the Cybathlon in Zurich with their Scalevo wheelchair. This is a competition where people with disabilities compete against each other. Technical aids are not only permitted but actually encouraged. After all, the intention of this event is to motivate researchers and engineers to invent better and more affordable wheelchairs, prosthetics and other aids.

### A vision for the future

The Scalevo team is sure: They want to win the Cybathlon in the wheelchair category. Some modifications to their device are necessary. The suspension of the caterpillars has to be made stiffer, the operation more intuitive, the reliability has to be increased. Then everything is possible. Perhaps the young inventors will found a start-up, who knows? The idea is in place. If they do, the new wheelchair with its integrated caterpillar might be available on the market soon. Astonished glances? That’ll be a thing of the past when it becomes normal that wheelchair users cruise up and down stairs as if it is the most natural thing in the world. ■

Photos: maxon motor ag, Scalevo, Alessandro della Bella



Raffael Künzi and the project team master the obstacle course during the test run for the Cybathlon competition.

### Cybathlon 2016

At the Cybathlon, competitive sport meets state-of-the-art technology. Parathletes compete against each other in six disciplines. Among other events, there is an obstacle course for motorized wheelchairs and for athletes with active leg prosthetics. What’s disallowed at the Paralympics is more than welcome at the Cybathlon: state-of-the-art technology.

The Cybathlon is a project of ETH Zurich and will take place for the first time on October 8, 2016. Professor Robert Riener, the initiator of the event, says: “We want to reduce the barriers between the public, people with disabilities, and science.” Until now, more than 50 teams have registered, mostly members of research institutions. The media resonance is large and there are already countries that are interested in hosting the Cybathlon 2018 and 2020.







**maxon EC 45 flat**  
The brushless EC 45 flat motor drive delivers 50 watts of power, at a diameter of 45 millimeters. The drive delivers high torque and needs very little installation space. The motors are integrated into the 18 drive units of the robot, which are installed in the leg joints.

# Intelligence on six legs

Hector looks like a giant stick bug. An extremely lightweight exoskeleton and elastic joints turn the robot into a climbing expert. In the six legs, maxon drives provide the robot with a flexible gait.

**W**hen Hector carefully negotiates an obstacle course, it has an elegance that hardly any other robot can rival. The Biomechatronics research group of Bielefeld University, led by Prof. Dr. Axel Schneider, developed this six-legged walking robot using a stick bug as a model. The total length of the robot is roughly 90 centimeters – a giant stick bug. The project's goal is to better understand the gait of these insects and make the underlying coordination principles usable for technical systems. The research team also wants to investigate fundamental concepts for controlling elastically actuated robotic systems.

The extremely light exoskeleton consists of carbonfiber-reinforced plastic (CFRP). All drive parts and the connections between the leg segments were designed and fabricated in-house in Bielefeld. They are made of aluminum alloy. The unique features of this robot, which weighs 12 kilograms, are the

## Hector has basic intelligence.

multitude of sensors with which it is equipped and its biologically inspired, decentralized control principle. With its specially designed drives and sensors, it can adapt to the ground conditions while walking. Hector is currently capable of negotiating slightly uneven terrain and overcomes smaller obstacles, such as steps, without difficulty.

### One leg – three maxon motors

Each leg of the walking robot has three joints, so that the movements of 18 joints have to be controlled simultaneously. Each joint is equipped with a brushless maxon EC 45 flat motor. These 50-watt drives are custom units without a lateral connection board. The 18 leg joints are controlled using biologically inspired algorithms. For this purpose, the drive electronics and their controls are embedded in the drives. To make the drives elastic, special elastomer couplings, custom-designed for this purpose, were integrated directly into the drives. The research team needed a motor

that delivers high torque while being small and lightweight. “The motors also had to be as short as possible, because the resulting length of the overall drive limits the legs’ range of motion, among other things. This is why we chose the EC 45 flat,” explains research team member Jan Paskarbeit, who designed and built Hector.

### Basic intelligence

Hector's intelligence is still vastly inferior to that of insects. However, it already has to process complex sensor data for the leg coordination. Hector is able to walk independently and responds to obstacles. “You can't deny that even an insect is intelligent, in a very basic way. Similarly, Hector also displays simple intelligent behavior. One of many important properties of intelligent behavior is, for example, the ability to plan ahead. Initial versions of a “higher” robot control are currently being tested on the system, with the purpose of giving the robot simple planning capabilities – making it more intelligent, so to speak,” says Paskarbeit. Until 2017, the walking robot will be equipped with additional abilities over the course of a collaborative project hosted by the Bielefeld-based Center of Excellence for Cognitive Interaction Technology. ■



Download tablet issue 2 // 2015  
to see how Hector masters difficult  
terrain. [magazin.maxonmotor.ch](http://magazin.maxonmotor.ch)



# Win a Sphero Ollie robot



Sphero Ollie is a zippy single-axis robot that is controlled by cell phone via a Bluetooth interface. Robust, fast, playful.

Quiz question

## How much maxon is in Romeo?

Tell us how many DC motors of maxon can be found in Romeo, the nursing robot of the future. E-mail your answer to [driven@maxonmotor.com](mailto:driven@maxonmotor.com) and win one of three Sphero Ollie robots. *The deadline for participation is February 28, 2016.*

### Imprint

**Published by:** maxon motor ag  
**Project manager:** Michel Riedmann  
**Editors:** Stefan Roschi, Anja Schütz  
**Image editing:** Heiner Eugster

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**Realization:** Infel Corporate Media  
**Project manager and editor:** Bärbel Jördens  
**Design:** Peter Kruppa (Art Director), Marina Maspoli  
**Photo editors:** Diana Ulrich

**Proofreading:** Claudia Marolf

**Printing:** Druckerei Odermatt AG

**Frequency of publication:** Twice per year as iPad, Android and Windows apps, and as a print magazine (April/November)

**Languages:** German, English

**Print run:** 10,500 (DE), 4,500 (EN)

Photo: Sphero

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