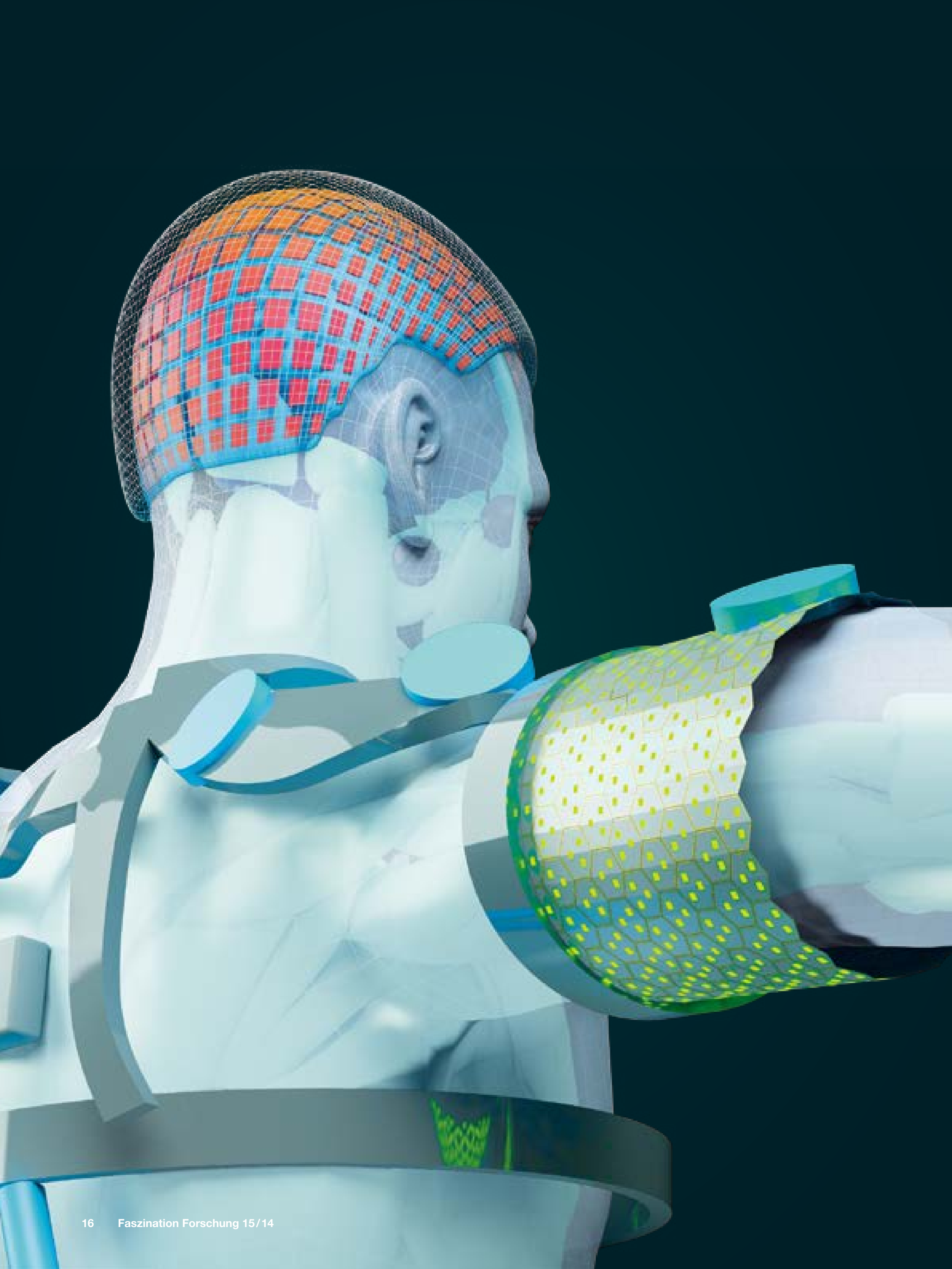


The Walk Again Project aims to overcome paralysis with the help of a phenomenal amount of smart technology. It utilizes an exoskeleton controlled by the thought of a paralyzed person. An electrode cap detects the brain signals, and a computer integrated into the suit converts these into commands for movement.

Picture credit: ediundsepp

Exoskeleton Enables Paraplegic **Man to Walk**

The first kick of the 2014 soccer World Cup in Brazil was taken by a paraplegic man wearing a mind-controlled robotic suit known as an exoskeleton. Prof. Gordon Cheng, head of the TUM Institute for Cognitive Systems, played a key role in this global premiere.

Exoskelett lässt Gelähmte gehen

Der 12.Juni, der Tag der Eröffnungsfeier der Fußballweltmeisterschaft 2014 in Brasilien, ist für Prof. Gordon Cheng, Leiter des Instituts für Kognitive Systeme an der TUM, etwas Besonderes. Erstmals hat ein gelähmter Mensch einen Roboteranzug, als Exoskelett bezeichnet, mit seinen eigenen Gedanken so gesteuert, dass das vom Exoskelett geführte Bein den WM-Fußball angestoßen hat. Die geglückte Mind-Maschine-Kooperation ist das Ergebnis einer mehrjährigen internationalen Zusammenarbeit, an der Cheng mit seinem Institut maßgeblich beteiligt war. Die Steuerung des Exoskeletts durch die Gedanken des Patienten ist wegen des Prinzips des „erweiterten Körperschemas" möglich. Der Patient sieht das Exoskelett als Teil seines Körpers an. Der in das Exosklett integrierte Computer ist so programmiert, dass er die Gedanken des Patienten, die mithilfe einer Elektrodenhaube abgeleitet werden, in Befehle für das Exoskelett übersetzen kann.
An bestimmten Teilen wie den Fußsohlen ist das Exoskelett mit einer künstlichen Haut überzogen, die Tastsinn vermittelt. Sie wurde in Chengs Institut entwickelt. Jede ihrer 160 in flexiblen Kunststoff eingebetteten Basiseinheiten ist mit einem Mikroprozessor sowie mit sechs sich selbst organisierenden Sensoren bestückt. Sie erkennen, wenn sie beschleunigt, berührt, erwärmt werden oder sich zum Beispiel einem anderen Objekt wie dem Fußboden nähern. Dem Patienten wird dies in weniger als 300 Millisekunden anhand von Vibrationen an seinen Armen vermittelt, denn er muss wissen, welche Bewegung der Roboter gerade ausführt. Das Gehirn lernt diese Signale richtig deuten.
Die künstliche Haut eignet sich auch für Industrieroboter. Sie stellen derzeit für die in ihrer Nähe arbeitende Menschen eine Bedrohung dar und sind deshalb hinter Gittern und Laserschranken untergebracht. Eine auf der Roboteroberfläche aufgebrachte künstliche Haut könnte mithilfe ihrer Sensoren eine Kollision vorzeitig erkennen und vermeiden.

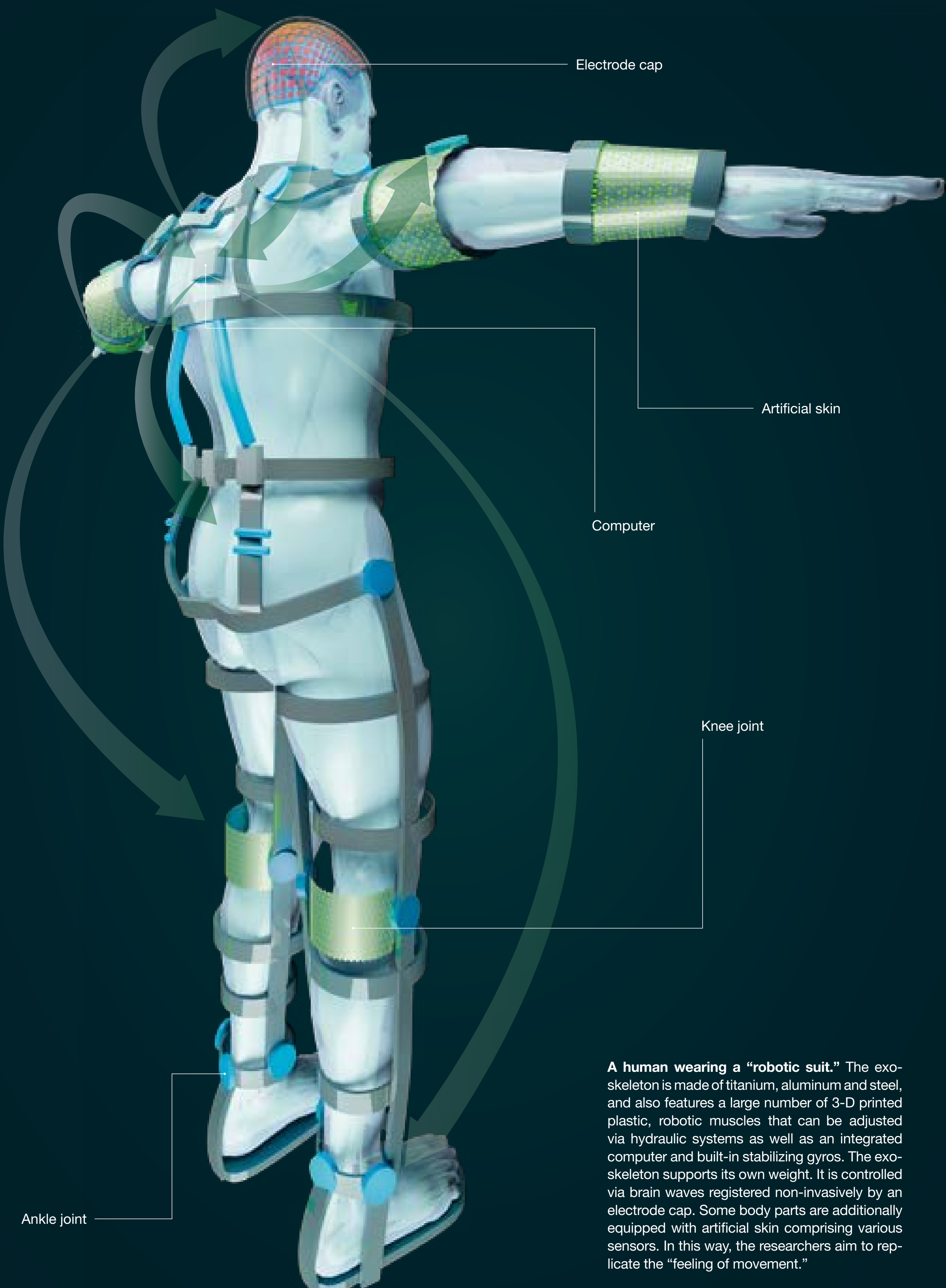
Gerlinde Felix

Link

www.ics.ei.tum.de

My interviewee's eyes shine with delight when the stadium in São Paulo, Brazil, appears in the huge digital photo frame in his office. The frame shows over a thousand images from more than four years' work. But this particular image is something special. It is "the" picture for Gordon Cheng, Professor of Cognitive Systems at TUM. And June 12, 2014, the day of the opening ceremony of the soccer World Cup in Brazil's São Paulo, is a day he will never forget. "Watching Juliano Pinto kick that World Cup ball was a fantastic and hugely satisfying feeling," explains Cheng with a smile on his face. In itself, kicking a soccer ball is nothing special. However, 29-year-old Pinto has been paralyzed for a number of years. The fact that he was able to independently kick the ball despite his paralysis is all down to the exoskeleton that he was wearing and controlling with his mind. The exoskeleton is a kind of robotic suit capable of supporting its own weight. It is made of titanium, aluminum and steel, and also features a large number of 3-D printed plastic, robotic muscles that can be adjusted via hydraulic systems, and an integrated computer and built-in stabilizing gyros. Parts of the exoskeleton are even covered by an artificial skin that transmits tactile signals to the user. "The skin provides the user with feedback, ▷

"When we drive a car, the car becomes an extension of our body schema. When we eat, it's the knife, fork or chopsticks. It's the same with the exoskeleton." *Gordon Cheng*



A human wearing a "robotic suit." The exoskeleton is made of titanium, aluminum and steel, and also features a large number of 3-D printed plastic, robotic muscles that can be adjusted via hydraulic systems as well as an integrated computer and built-in stabilizing gyros. The exoskeleton supports its own weight. It is controlled via brain waves registered non-invasively by an electrode cap. Some body parts are additionally equipped with artificial skin comprising various sensors. In this way, the researchers aim to replicate the "feeling of movement."

Picture credit: ediundsepp

Fantastic footwork by an exoskeleton. Since January 2014, the Walk Again Project has trained eight paralyzed persons in Brazil to move with the exoskeleton. One of them used the suit to take the World Cup's first kick – just with the help of mind power and supported by innovative technology. Lead robotic engineer Gordon Cheng and research assistant Philipp Mittendorfer were watching the training sessions and continuously worked to improve the system.

Picture credit: Eckert

Gordon Cheng holding parts of a robot with artificial skin on its surface. The artificial skin makes robots more sensitive and human-like. It will make it easier for humans to work or live with robots in a shared environment. One example is factory robots, which today work behind bars and laser barriers.

telling them indirectly, for example, that the robotic leg – and therefore the patient's own leg – has touched the ground," adds Cheng.

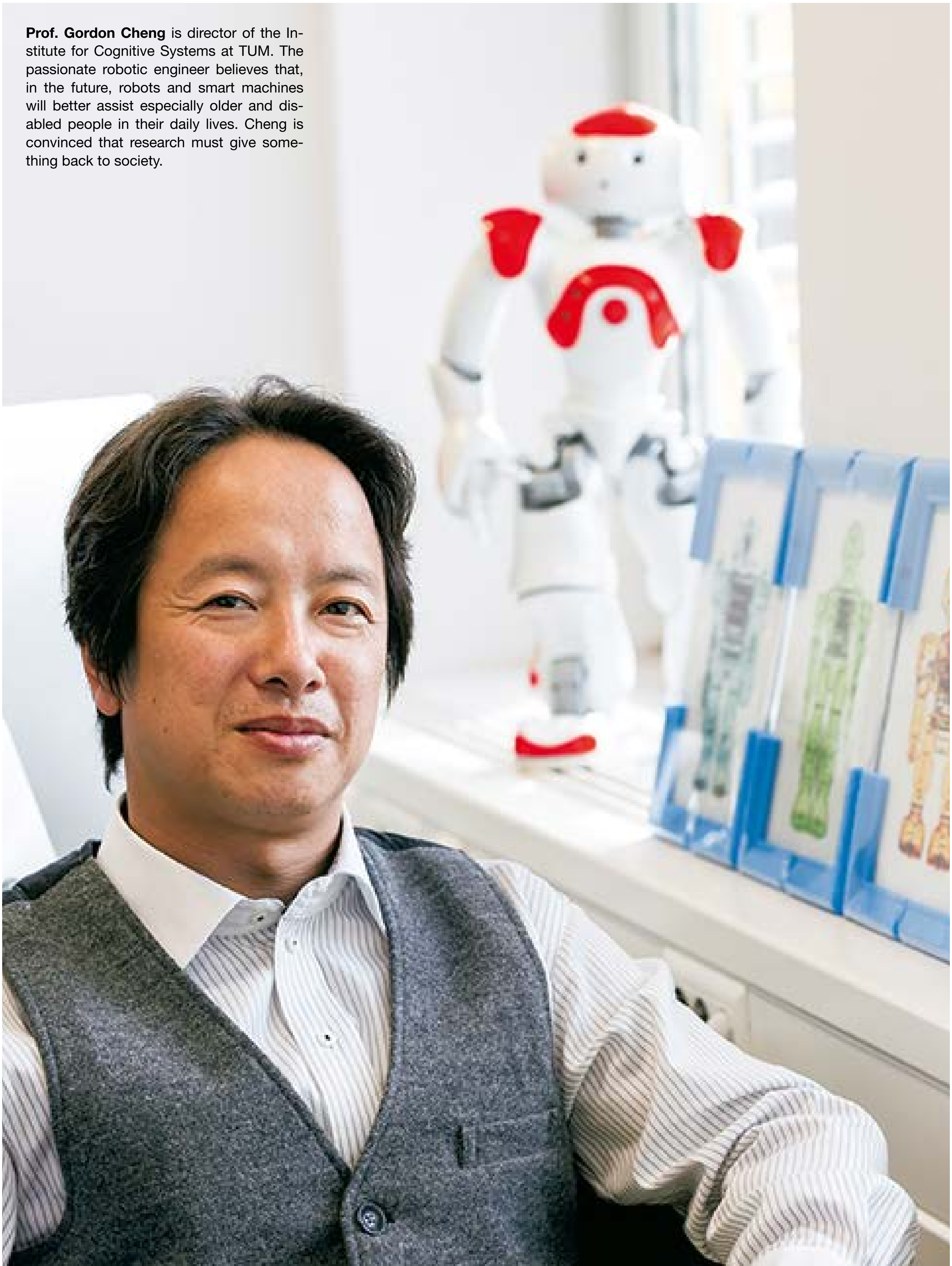
Tactile stimulation for robots

The mind-controlled exoskeleton is the product of many tough years of international collaboration between experts in the fields of neuroscience and cognitive technology. Gordon Cheng at TUM has been a key player in this initiative together with project leader Miguel Nicolelis, neuroscientist and physician at Duke University in Durham, North Carolina, in the US. The battery-powered exoskeleton is the result of collaboration between all project participants. However, the artificial skin that transmits tactile signals was developed primarily by scientists in Munich. Cheng came to Munich to hold a lecture just over four years ago. The university was so impressed by his work that it offered him a professorship in cognitive systems. He was very tempted by the offer but would not commit without consulting his wife. Luckily, she said yes. The university created a new chair for Cheng, the Institute for Cognitive Systems (ICS). One of the ICS's core goals was the creation of artificial skin for robots. Cheng was unfamiliar with the German system, so he had no idea how much work was waiting for him in Munich. He started from scratch with just eight employees at the beginning. Later, in the critical phase of the project, he was flying back and forth between Munich and São Paulo to tailor the exoskeleton and artificial skin to the requirements of the patients in São Paulo. It was a herculean task to have everything ready by June 12, 2014. Today he has more than double the number of employees with new people joining all the time. Yet Cheng still has time for visitors – whether it's preschoolers or school children looking to find out more about science, or the French prime minister and his entourage. In fact, he can't help smiling when he talks about that visit, when more than a dozen limousines and two buses full of people brought Karlsstraße in Munich to a standstill. "We like what we are doing and are always happy to show it to other people. Luckily, we didn't have to deal with the chaos caused by our guests."

Humanoid robots and neuroscience

Cheng is a true globetrotter. He was born and spent his first years in Macau, when it was still a Portuguese colony. Later, he went on to study information sciences and complete a PhD in systems engineering in Australia. From 2003 to 2008, Cheng founded and headed up the Department for Humanoid Robotics and Computational Neuroscience at the Institute for Advanced Telecommunications Research in Kyoto, Japan. During this time, he was also responsible for the neuroscientific "Computational Brain" project. It was during a symposium in Kyoto that he met Miguel Nicolelis. Both scientists were impressed with each other's work. Before taking the professorship in Munich in 2010, Cheng worked as a visiting professor in the US and France, and also at the Edmond and Lily Safra International Institute of Neuroscience in Natal, Brazil. The institute was founded by Nicolelis in 2005. He specifically chose to locate it in one of the poorest regions in Brazil. In addition to the actual research ▷

Picture credit: Eckert



Prof. Gordon Cheng is director of the Institute for Cognitive Systems at TUM. The passionate robotic engineer believes that, in the future, robots and smart machines will better assist especially older and disabled people in their daily lives. Cheng is convinced that research must give something back to society.

Picture credit left: Eckert, right: KUKA Systems GmbH institute, the site also houses a clinic that offers free, prenatal check-ups and a science school for 1,500 children. Cheng taught at the school for one month.

The first step toward an exoskeleton

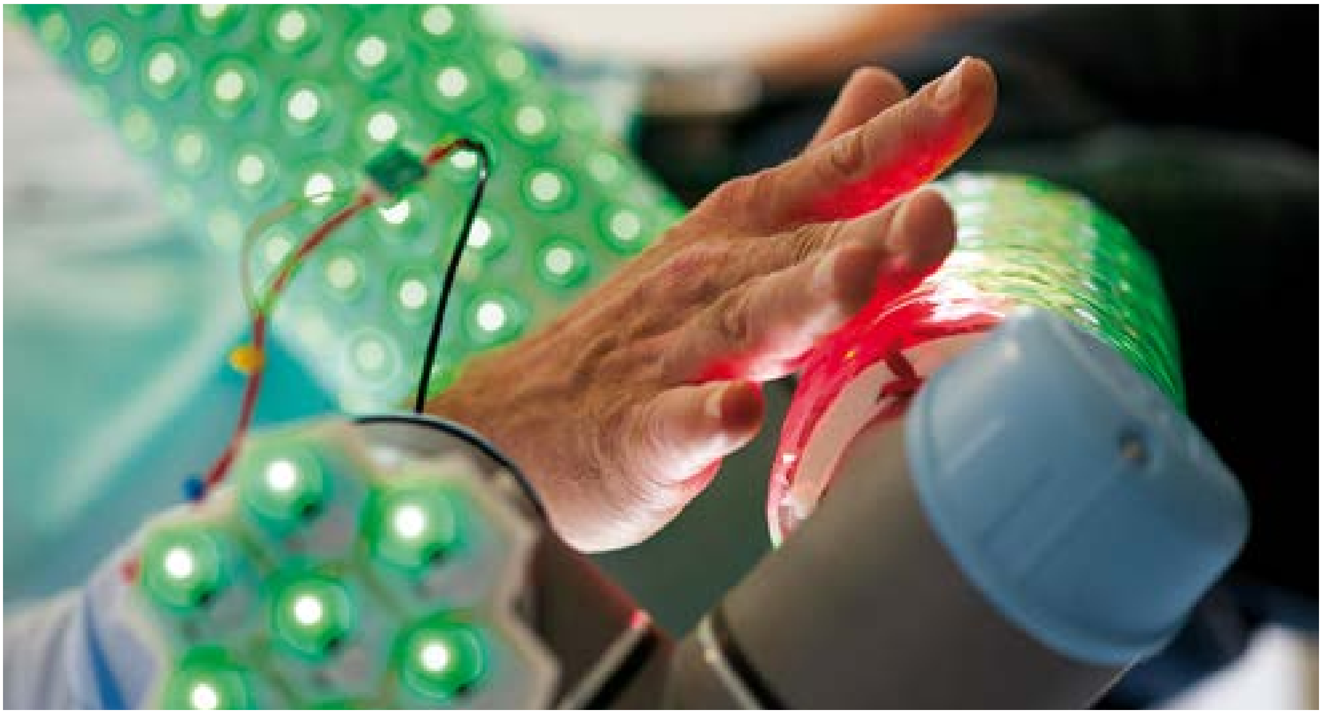
Cheng and Nicolelis started carrying out initial trials for the Walk Again Project back in 2008 in North Carolina. The first steps were made by a female rhesus macaque monkey called Idoya. Nicolelis and his team implanted electrodes into her brain. As soon as Idoya was able to walk upright on a treadmill, the team recorded the signals emitted by her brain and mapped them against slow motion recordings of her movements. The scientists were able to use this data to identify the commands associated with leg movement. The commands from the monkey's brain were transmitted in real time to Japan. There, Cheng fed them into a humanoid robot, which started to imitate Idoya's steps. The robot's leg movements were then played back live to Idoya, who learned to control and improve them. When Nicolelis's treadmill stopped, Idoya also stopped moving, but kept her eyes firmly fixed on the monitor. The robot in Japan kept walking for another three minutes. This could only have been done by Idoya herself. She regarded the robot's movements as her own and was able to control its steps just by using her mind. "This was possible only because the robot had become part of her body schema," Cheng enthuses, clearly still impressed by the rhesus macaque's intelligence. "When we drive a car, the car becomes an extension of our body schema. When we eat, it's the knife, fork or chopsticks. It's the same with the exoskeleton."

Mind and body working together

Eight paralyzed Brazilians aged between 20 and 40 made it through to the final selection for the Walk Again Project in São Paulo. For these eight people, the exoskeleton became a part of their body. But it took a long time to learn how to deal with the new technology. The learning process started on a treadmill. The participants were placed in a harness and their legs supported by a frame. Their brain activity was measured noninvasively along the scalp using electrode caps on their heads and electroencephalography (EEG). The mechanical frame was used to walk the patients' legs. While this was happening, the participants were asked to concentrate hard on wanting to walk. The resulting brain wave pattern was similar in all eight patients. In the next phase, the patients had to wear the electrode cap and start training with a virtual computer simulation. Instead of their own legs, the participants saw animated legs below their waists. Whenever they thought about walking, standing or kicking in the right way and imagined making the corresponding movements, ▷

Keeping robots on their feet with artificial skin

Heavy-duty, walking industrial robots currently pose a risk to people working in their immediate vicinity. They have the potential to cause serious injuries, for example to an individual's head or chest. Most industrial robots therefore work behind bars and laser barriers. However, this takes up space in production halls, and limits the ways in which robots can be used. Covering the surface of robots with artificial skin could change this. The artificial skin is made up of self-organizing sensors that can detect and prevent collisions before they happen, making interaction between humans and machines safer. For this to become reality, however, the industrial robots have to be given information on the position of the sensors. This is not done manually, but by using self-organizing algorithms. "The robot then knows what it looks like within just a short time," explains Philipp Mittendorfer, a researcher who is writing a PhD thesis about artificial skin. The algorithms automatically determine the position of sensors on the robot's surface. Other algorithms determine structural dependencies between the robots' joints and body parts, reconstruct the shape of body parts in 3-D and investigate the robot's kinematics. The robot can use its own sensors to get to know itself. "The exoskeleton requires only part of the functionality possible with artificial skin. With industrial robots, however, we will be able to unlock the technology's full potential," continues Mittendorfer. The skin can be used to quickly integrate industrial robots into production sites – a concept that is being investigated in the EU-funded "Factory-in-a-day" research project.



Touching the artificial skin of a robot part. The multimodal-cellular skin is named CellulARSkin. It consists of several hexagonally shaped unit cells, each featuring multiple sensor modalities. The artificial skin makes it possible to enrich robot interactions through a multimodal sense of touch.

their virtual legs made the exact same movements. “The patients were more or less learning a new language. We can do this only because our brains are unbelievably adaptable,” explains Cheng. From January 2014 on, the participants started training using an exoskeleton with an integrated computer. The signals from the brain are translated into specific commands that the computer sends to the exoskeleton. “An incredible amount of data was collected, decoded and translated into movement commands for the exoskeleton. This all had to be categorized and the computer programmed correspondingly,” continues Cheng.

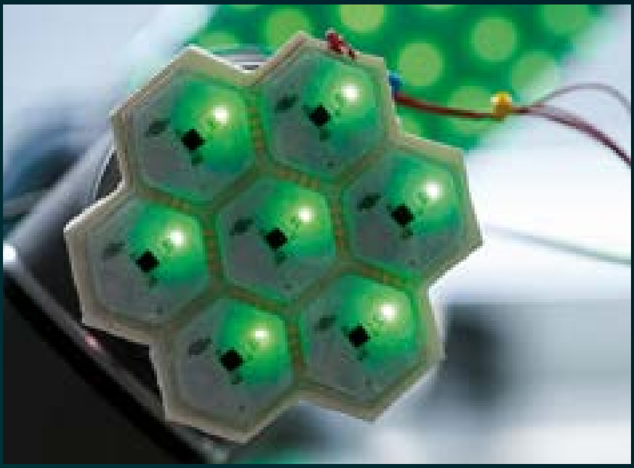
Artificial skin stabilizes exoskeleton

As far back as 2008 however, the researchers realized that something was missing. The participants need continuous feedback on the current position of the robotic legs and, during training on the treadmill, with virtual legs. They have to know what movement the robot is making at all times; otherwise the exoskeleton could fall over. What they needed were sensory receptors. This is where CellulARSkin comes in. The artificial skin was developed at the ICS to provide tactile sensations. It comprises a large number of hexagonal printed boards approximately the size of a two-euro coin. Each one features an energy-saving microprocessor and six sensors. Four of these have separate functions to detect changes in speed, temperature and touch and to sense proximity to other objects in three-dimensional space, for example when they are close to or moving away from the ground. The exoskeleton is currently equipped with around 160 of these elemental cells. And since they are not available on the market, the cells had to be developed at the ICS. The hexagonal elemental cells are embedded in flexible plastic and can be connected to form honeycomb-like mats. What makes the skin so revolutionary and exciting is that each cell works locally. The sensors organize their network themselves and pre-process data at this level, which significantly reduces the data transfer load to the central computer. This is made possible by a set of algorithms developed specifically for this application. This localized approach means that the sensors are resistant to external influences and component failure – if one component malfunctions, the rest of the artificial skin will continue to work. CellulARSkin is also placed on the soles of the exoskeleton’s feet. The sensors here send information to a central control unit when the sole of the foot is just about to touch the ground, when it makes contact with the ground and when it is just leaving the ground. The participants feel these signals via small motorized metal cylinders attached to their arms. When the virtual foot touches the treadmill or the robotic

Picture credits: Eckert/graphics: ediundsepp (source: TUM) foot touches the ground, the cylinders start to vibrate less than 300 milliseconds after contact. “The delay cannot be any longer. Otherwise the brain would not be able to cope, and this could be very stressful for the participants. Our brains learn very quickly and can interpret these signals correctly within a very short time,” explains the Munich-based researcher. The artificial skin enabled the participants’ brains to learn more effectively while moving on the treadmill and in the exoskeleton. Around 80 of the 160 elemental units are used to make sure that the 42 kg exoskeleton is not pressing down too hard on any part of the users’ bodies.

Affordable technology

For Cheng, June 12 was not the end of his work, but just the beginning. “We still have a long way to go,” he adds. And he has many new ideas to try out. “We will be improving the exoskeleton even more and harnessing new technologies to bring down production costs.” Cheng would like to see the exoskeleton used by as many paralyzed people as possible. He also believes it can help patients with other movement disorders. “Science can really give something back to society here.” Cheng and Nicolelis are very much on the same track here. With all this going on, it’s hard to see how Cheng finds the time to watch football with his eight-year-old daughter, an ardent fan of FC Bayern and goalkeeper Manuel Neuer. But he is a pioneer in the truest sense of the word: “It’s something completely new for me,” he says. And new is something he is always willing to try. *Gerlinde Felix*



Each hexagonal cell of the artificial skin comprises four sensors that measure pressure, proximity, temperature and vibration as indications for touch. The interconnected cells pass electrical signals via varied pathways through the entire skin to and from the central computer.