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Getting **a Grip**

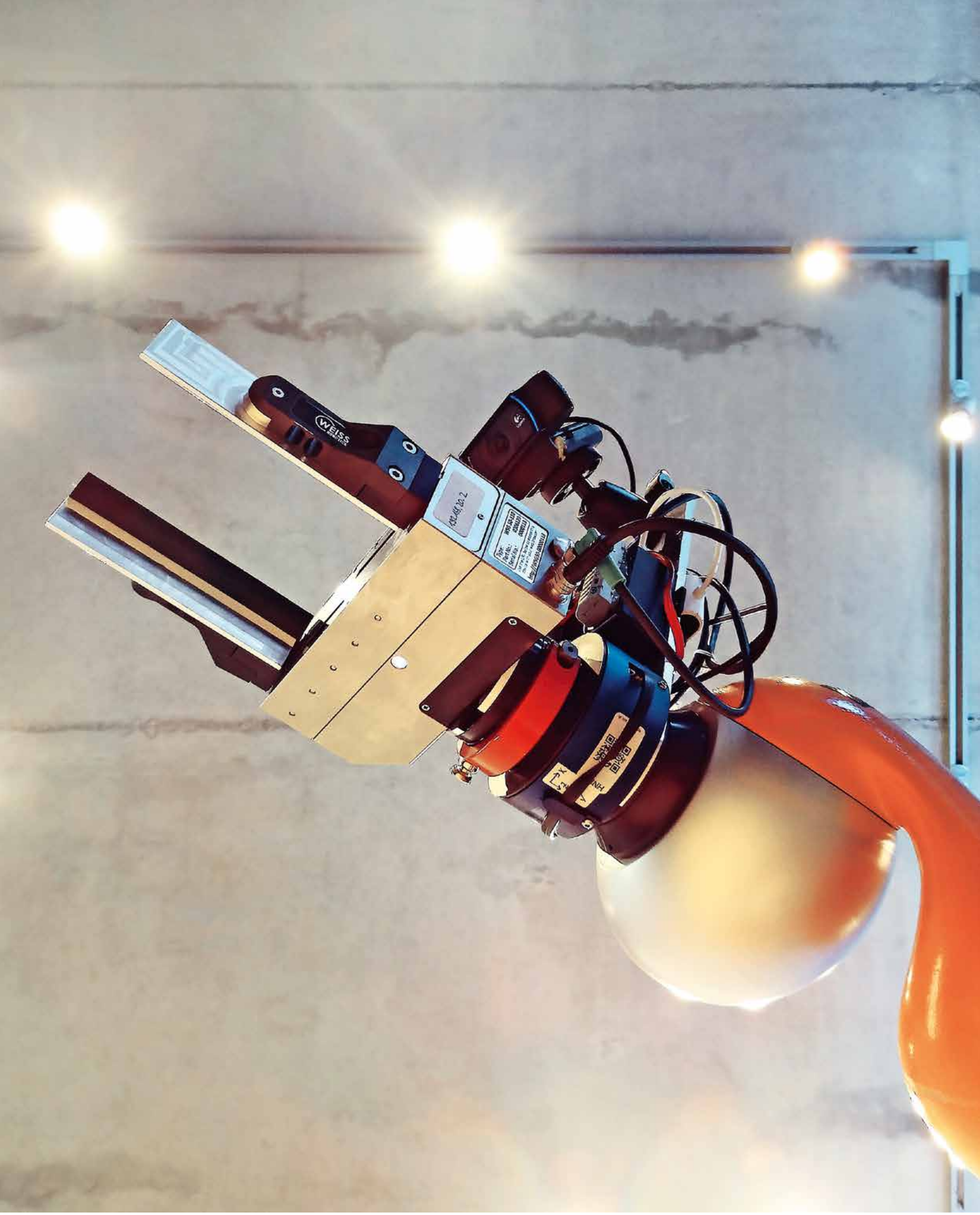
Industrial robots are engineered for extreme levels of precision, using sophisticated sensors to grab and manipulate objects with millimeter accuracy. However, they are also very expensive. That fact prompted Prof. Eckehard Steinbach and his team to develop a light and affordable robot that doesn't need costly sensors thanks to camera-enabled motion control. This machine is particularly suitable for smaller industrial companies that are currently priced out of the robot market.

Tim Schröder

Einfach greifen

Industrieroboter sind Präzisionsmaschinen, die dank ausgeklügelter Sensorik millimetergenau zupacken können. Doch diese Geräte sind teuer. Das Team von Prof. Eckehard Steinbach hat deshalb einen leichten und erschwinglichen Roboter entwickelt, der seine Bewegungen mit einer kleinen Kamera kontrolliert – und ohne teure Sensoren auskommt. Das Gerät eignet sich vor allem für kleinere Industrieunternehmen, die bislang wegen der hohen Kosten auf Roboter verzichten.

Moderne Industrieroboter sind Hightech-Maschinen. In ihren Gelenken sitzen jede Menge Sensoren, die Kräfte oder Drehmomente präzise messen. Solche Roboter können einen Punkt im Raum auf wenige Zehntel Millimeter genau anfahren, ohne dass etwas wackelt. So ein Roboter-Arm für die Industrie kostet mitsamt der Sensorik aber schnell einmal 100.000 Euro oder mehr. Für kleine Unternehmen sind Roboter damit oftmals unerschwinglich. Steinbach, Leiter des Lehrstuhls für Medientechnik der TUM und sein Doktorand Nicolas Alt haben deshalb ein kostengünstiges Robotersystem für kleine und mittelständische Unternehmen entwickelt, das eine Bewegung nicht mithilfe vieler teurer Sensoren überwacht. Stattdessen wird das Greifen ganz einfach mithilfe einer kleinen Kamera beobachtet und gesteuert. Das ROVI (Roboter Vision) genannte System nutzt einen Greifer, dessen Backen aus einem robusten Gummi bestehen. Greift der Roboter, werden die Gummibacken langsam zusammengepresst. Und diese Verformung nimmt die Kamera wahr. Damit kann das System ganz ohne Kraftsensor sehr genau einschätzen, wie stark der Gegenstand gepackt wird. Zugleich beobachtet die Kamera die Verformung des Gegenstands, um zu verhindern, dass dieser zerquetscht wird. Da sich jeder Gummityp bei einer bestimmten Kraft anders verformt, wird dieser vor Beginn der Experimente genau vermessen. Aus der Verformung des Gummis im Kamerabild kann der Computer später die momentan aufgewendete Kraft ermitteln. In ersten Experimenten konnten die Forscher sogar weiche Plastikflaschen greifen; eine Aufgabe, an der herkömmliche Roboter oftmals scheitern. Steinbach geht davon aus, dass ROVI nur den Bruchteil eines herkömmlichen Industrieroboters kosten wird. Das ist entscheidend, um klein- und mittelständische Unternehmen zu erreichen. Derzeit wird ein Prototyp entwickelt, der genau auf industrielle Applikationen zugeschnitten ist. Denkbar ist, dass ROVI beim Sortieren von Kleinteilen oder beim Abpacken von Artikeln für den Versand eingesetzt wird. Eine weitere Anwendung wären Roboter für den Spiele- und Unterhaltungsmarkt, beispielsweise für Roboterbausätze. □


WEISS

A low cost robot gripper with precision: The ROVI system employs gripper jaws made of rubber. When it grips an object, the rubber is compressed and a camera registers this deformation.

The aim is to develop a robot gripper that operates with precision but costs just a fraction of the price of an established industrial robot.

If you would like to test a robot's grip, just hand it an open detergent bottle or – even better – a Capri Sun juice pouch with a straw. The robot will obediently latch on to what you give it – and then, in most cases, make a huge mess. Today's robots can securely grasp firm objects as often as 10,000 times a day with sub-millimeter precision, but pliable objects such as plastic bottles and drink pouches still pose an insurmountable challenge for many of them.

Robots nowadays obviously feature the most sophisticated of technologies. Their joints contain numerous sensors that precisely measure forces and torques, and they can be positioned with an accuracy of a few tenths of a millimeter without wobbling. They can lift televisions or even entire car parts with ease and set them down with the utmost care. However, complete with sensors, the price of this type of industrial robot arm quickly soars to 100,000 euros or more – which usually proves prohibitive for smaller companies. That is why, some time ago, Eckehard Steinbach from TUM's Chair of Media Technology (LMT) began a new project along with his doctoral student, Nicolas Alt. They set out to develop an alternative robot gripper – a device that would operate with precision and dexterity but cost just a fraction of the price of an established industrial robot.

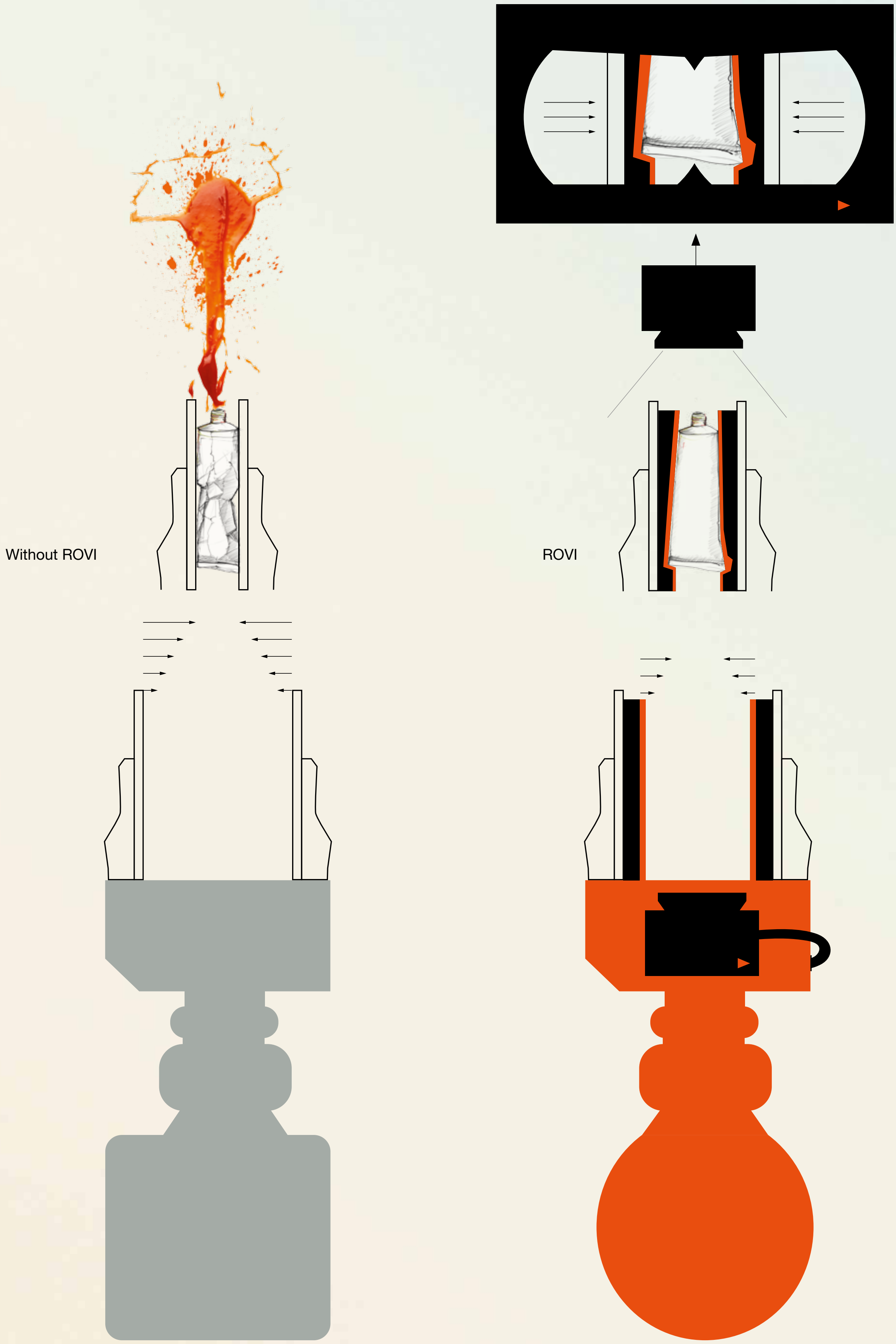
The team defined two clear design criteria at the outset: the new robot should be small and streamlined in order to reduce mass and thus cut manufacturing costs, and it should not involve expensive sensors or complex cabling. "Our aim was to develop a gripper concept that would also enable small and medium enterprises to automate simple and repetitive tasks," confirms Eckehard Steinbach. "A cost-effective robot that could sort small parts or help pack items for shipping, for instance."

Gripper in focus

It was only a matter of time before the researchers had their brainwave: why not imitate the way people do it? When a person grasps something, they look at what they are doing. They size up the situation, set their sights on the object in question, put out their hand and then take hold. So the new robot should do the same. Instead of monitoring every motion with several expensive sensors, the device should simply use a small camera to observe and control its grip. The colleagues applied to the European Research Council and received funding in the form of an ERC Proof-of-Concept grant – not least because the focus on small and medium-sized enterprises means the robot has significant commercial potential.

Nicolas Alt focused his doctoral thesis on the development of this robot. And the fruits of his work with Steinbach over the past few years are certainly impressive. Extending beyond a single robot arm that can grip specific objects, the outcome is new concept where robots simply watch ▷

Picture credit: Bauer



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Robots can precisely grasp firm objects but pliable objects still pose a challenge – unless they are equipped with force and pressure sensors. The ROVI system determines the force from the deformation of gripping jaws made of rubber, which is picked up by a camera.

what they are doing. The machines in Steinbach's lab can use a bottle opener to push off crown caps, nimbly move objects to one side and even unscrew pliable plastic bottles – a challenge that continues to elude many more established machines. The duo calls their optical system ROVI – which simply stands for "robot vision".

Defined deformation

At first glance, the ROVI system seems surprisingly simple. The jaws of the gripper are made of robust rubber. When the robot grasps something, the rubber jaws are slowly compressed – and the camera picks up on this deformation. This means the system does not need a force sensor to assess with precision how hard the object is being gripped. At the same time, the camera also monitors distortion of the object, to avoid it being squashed. Since various types of rubber deform differently under any given force, this behavior is precisely measured prior to the experiments. The crucial factor is the extent to which the polymer is deformed by a specific force. "So we generate a characteristic curve that gives a very accurate picture of the plastic," explains Alt. "Based on the deformation of the rubber in the camera image, the computer can later determine the force applied at the time."

The measurements for bottle opening work a little differently. For this experiment, Alt attached the opener to the end of a metal rod. Once the opener was latched onto the crown cap, the robot slowly began to raise the rod, which was thus subject to gradual deformation. To measure this with the camera, Alt stuck a printed pattern to the rod. The further the rod was bent, the more distorted this pattern became in the camera image. In this case, then, ROVI deduced the force applied from the distortion of the photo. "The same principle could be used to measure the deformation of a robot arm when lifting a weight," adds Steinbach. "We could stick image templates to the joints and then monitor their distortion by camera." And the price of this would be negligible, since small cameras are already available for just a few euros.

The ROVI system is even able to guide small assistive robots. Vacuum cleaning robots, for instance, often use infrared beams to scan their surroundings. But infrared does not always work with transparent objects. Put a glass vase in the path of an assistive robot and the vase may well end up smashed. For this reason, Alt equipped his robot with a type of plastic bumper. As with the gripper jaws, a camera was used to monitor deformation of the plastic in this experiment. When the robot encountered an object, the system was well able to determine whether measured force could be applied to move the item out of the way or whether the robot needed to navigate its way around the immobile object.

Assembly line assistance

Needless to say, pushing vases out of the way is not the researchers' main preoccupation here. One of their aims is to advance ROVI to the point where it can perform small tasks for industrial companies with high precision and speed. "Of course, our optical system is not as accurate as a large industrial robot with sub-millimeter precision," concedes Steinbach. ROVI is not always on target with millimeter accuracy – it might be one or even two centimeters off. But that is not an issue, since the ROVI system continually checks itself. If the gripper is a little off the mark, the camera spots this and gives a command to correct the position. The correction process is so fast that ROVI exhibits smooth movement overall and the gripper reaches its target relatively quickly. This capability would be of particular interest if ROVI were to be used to pick and sort components on an assembly line, for instance. Steinbach also envisages applications in laboratories at research institutes and universities, where repetitive tasks such as pipetting fluids are currently still performed by lab technicians and students in many cases. An affordable ROVI would make an ideal assistant here. ▷

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Eckehard Steinbach

Prof. Eckehard Steinbach

Fostering young scientists

For Eckehard Steinbach, there are many reasons why he enjoys his work as a researcher – including the desire to discover new things. “But another important reason is definitely that I find working with young people extremely enriching. There are so many talented up-and-coming researchers – and I learn more myself with every doctoral candidate.” The ROVI robot gripper is an excellent example of this collaboration at work. Steinbach is an electrical engineer who has long been engaged in teaching machines to see – his focus lies on audiovisual media. And then he had the idea of incorporating touch in the form of gripping. But using a rubber gripper and monitoring its deformation by camera to measure forces was the brainchild of his postgrad.

“I can only encourage young people to pursue a scientific career,” Steinbach confirms. “There are now so many more opportunities to convert your own idea from a research project into a commercial product.” He feels the prospect of starting their own company can give huge impetus to young people in their research work. And, he observes, they can now take advantage of targeted training in entrepreneurial skills, for instance through events run by UnternehmerTUM (Center for Innovation and Business Creation at TUM), bringing participants up to speed on business plans or patent law.

Steinbach’s own fascination with mathematics, physics and technology was evident at an early age. As a teen he was building his own amplifiers – for sound systems with proper power. Another thing that caught his enthusiasm early on was the international dimension of research – the opportunity to share scientific knowledge and tackle topics with people from other cultures and teams. Steinbach himself studied at the University of Essex in England and the ESIEE (Ecole Supérieure des Ingénieurs en Electrotechnique et Electronique) in Paris. He later took a postdoc job in the Information Systems Laboratory at Stanford University in the US. And today, flanking his professorship at TUM’s Chair of Media Technology, he is also foreign student advisor for his faculty and coordinator of international research partnerships, reflecting his commitment to sharing his overseas experiences with the next generation.

Picture credit: Bauer

Vacuum cleaning robots normally use infrared beams to scan their surroundings. But that does not always work with transparent objects.This robot is equipped with a type of plastic bumper. A camera monitors deformation of the plastic.

When the robot encounters an object, the ROVI system detemines whether measured force can be applied to move the item out of the way or whether the robot needs to navigate its way around it.

“Our aim is to build the ROVI prototype, so we can show just how well this technology works in real industrial applications.” *Eckehard Steinbach*

As with many other developments that look astoundingly simple at first, the devil is in the detail with ROVI. “We developed an entire toolbox of technologies for ROVI,” confirms Steinbach. The researchers first had to investigate the correlation between force and deformation. To describe this relationship mathematically, they carried out measurement experiments with an industrial robot equipped with force sensors. However, gripping was not the only aspect – they also had to cover image analysis. To interpret distortion on the photographs, for instance, ROVI needed a software system that could recognize templates and track their movements in the camera image. Another aim was dynamic and high-resolution analysis of the material deformation, which meant the researchers writing special algorithms. And both scientists were keen for ROVI to be able to identify transparent objects such as plastic bottles too. Traditional programs for recording surroundings with 3D cameras are not able to accomplish this, so they had to devise new algorithms here as well.

Lightweight and affordable

Steinbach anticipates that ROVI will cost just a fraction of the price of a conventional industrial robot – probably a few hundred euros. This is key to reaching small and medium-sized companies. So it comes as no real surprise that the European Research Council has agreed to fund Steinbach and Alt’s project for another 18 months. “We intend to use this time to develop a prototype that is precisely tailored to industrial applications,” reveals Steinbach. “At the same time, we will be conducting market analysis to ensure our plans remain in line with industry requirements.” To achieve this, Steinbach is currently seeking industry partners who see a need for a small and light ROVI system. Robots for the games and entertainment market would also be a potential application, for instance as part of robot kits.

ROVI’s future development path when ERC funding runs out has not yet been mapped. Steinbach could imagine bringing the robots to market via a start-up company or licensing the technology to larger robot manufacturers. “But for now our aim is to build the ROVI prototype, so we can show just how well this technology works in real industrial applications.”

Tim Schröder

Picture credits: Bauer