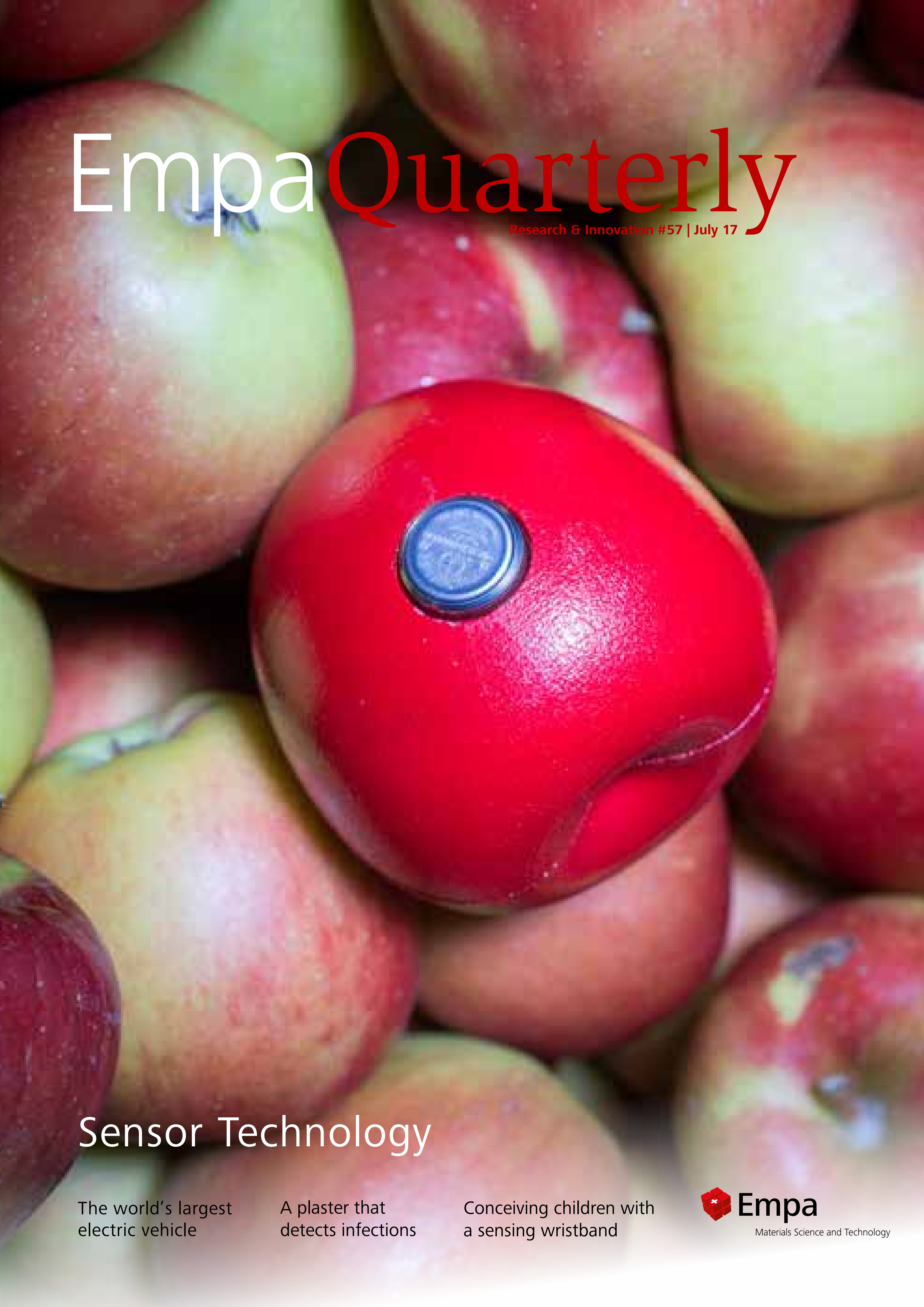

EmpaQuarterly

Research & Innovation #57 | July 17

Sensor Technology

The world's largest electric vehicle

A plaster that detects infections

Conceiving children with a sensing wristband

Empa
Materials Science and Technology

MICHAEL HAGMANN Head of Communications

Putting our feelers out

Dear readers

In the sober, facts-based world of science and engineering, feelings and sensations normally take a back seat – unless we're talking about sensors (from the Latin sentire for to feel, to sense), that is. These are usually electronic components that supply information on physical and chemical parameters in their surroundings. To a certain extent, they act as a scientist's sensory organ, helping to describe the changes in the world around us – or even in our bodies – as precisely as possible and thus understand them way better. Only if we comprehend and perceive our environment as fully as possible can we interact with it in a purposeful, meaningful way; only with sensors can technology really become "smart".

Sensors can be used to measure virtually anything, from relatively straightforward factors like temperature, pressure, brightness or acceleration to complex, abstract features such as the force between two atoms or the concentration of a particular metabolic product in biological samples such as saliva or blood serum. This makes sensors hugely important in numerous research fields – including at Empa, as the current issue of EmpaQuarterly illustrates.

An increasing number of sensors are especially being used in medicine to monitor physiological parameters. Functionalized fibers and textiles have proved themselves to be true "all-rounders" here, whether it be as a smart wound dressing to keep tabs on how the wound is healing, an ECG belt for cardiovascular patients or ammonia sensors that detect lung diseases by analyzing breath. Our "see-through" patient on the centerfold showcases other interesting applications (see pages 14-15).

Happy reading and until the next issue!

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Focus:

Sensors make us smarter

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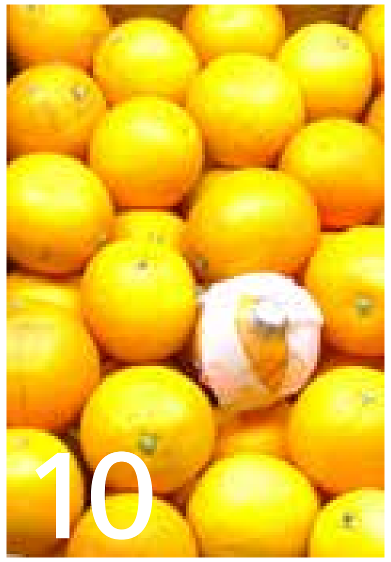

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Cover
A spy in the apple box: a Jonagold sensor, modeled exactly on its natural counterpart in terms of weight, water and sugar content, accompanies the fruit from the farmer to the grocer. This enables gaps in the cold chain to be detected and avoided. ***Page 10.*** *Photo: Empa.*

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Second lease of life for used batteries

What can we do with aging scooter batteries? Instead of scrapping them and recycling their components, the batteries could be left intact and re-used in a solar power storage cabinet. This is precisely what a pilot project by the Swiss Post and with participation of Empa is trying to do.

TEXT: Rainer Klose / PICTURES: Kyburz Switzerland AG, Ökozentrum

Swiss Post has a total of over 6,300 electric Kyburz DXP scooters in service.

Since January 2017, Swiss mailmen have been out on their rounds on Kyburz DXP electric three-wheelers as all gasoline scooters have been phased out. The first Kyburz three-wheelers were purchased in 2010. Meanwhile, the Swiss Post has a total of over 6,300 electric scooters in service. After eight years of hard work on behalf of the postal service day in, day out, however, the capacity of the batteries has dropped to between 70 and 95 percent, which means they are no longer powerful enough for the scooters. In the next few years, so much is certain, thousands of used batteries will accumulate. So what's to be done? Do they need to be scrapped? Or is there a more sensible idea to re-use them?

A pilot project initiated by the Ökozentrum in Langenbruck and backed by the Swiss Federal Office of Energy (SFOE) is now tackling this used-battery conundrum. The project is aptly entitled *Second Life*. The idea is for the batteries to carry on working in a stationary storage cabinet and store solar power. Electricity harvested from the roof can be used in the evening and at night. The problem: the system needs to be cheap, maintenance-free and reliable for a number of years – despite the "senior citizen batteries" running inside it, the remaining lifetime and efficacy of which can't be estimated with any degree of certainty.

Individual coaching for seniors

"Inexpensive is only possible if the used batteries don't have to be presorted," says Marcel Held, a battery expert from Empa's Reliability Center. "So we need a battery management that monitors every single one of the used batteries – and a storage technology that still works if 30 percent of the cells fail." Held is supervising the project scientifically and has been investigating the remaining capacity of around 150 batteries selected for the first experiment. He retained 12 at Empa for test purposes – four good ones, four medium and four bad. Over the next few months, they will undergo a series of charging and discharging cycles that correspond to between two and three years of actual service life. Held wants to see how much capacity remains, how the batteries can be used sparingly and how a battery cell reacts when it eventually goes belly up. "We'll monitor the batteries without taking them apart," says Held. "This will involve using impedance spectroscopy and taking x-ray images of the inner structure of the cells."

The experiment got underway in early 2017. There are already four prototype cabinets with used Kyburz batteries. The pilot storage facility is in use in the Umwelt Arena Schweiz in Spreitenbach and can be visited as part of the tour *A Glimpse behind the Scenes*. Three more are in operation in a post office in Neuenburg. The Ökozentrum Langenbruck developed the battery management system for the old batteries. If the pilot project goes as planned, the companies Batteriewerk AG and Helion Solar will be in charge of producing and selling the storage cabinets.

The main risk involves the price. "We aren't alone on the market," explains Michael Sattler, who is heading the project at the Ökozentrum. "There are over 50 suppliers of stationary energy storage devices. They all work with new batteries – and their prices are plummeting." It is already clear that the Second Life cabinet will not be considerably cheaper than a storage device with new batteries. "If we succeed, we'll be competitive on the market in the end," says Sattler. "In terms of the life cycle assessment, however, our storage device would undoubtedly have the edge." //

Solar storage
The Swiss Post's used batteries are installed in one of these storage abinets. Total capacity: 7 to 10 kWh.

World’s largest electric vehicle

A Swiss consortium of companies is constructing the largest electric vehicle in the world – in record time. The prototype is not intended as a dainty little exhibition piece for trade fairs, but rather for hard labor in the quarry. Experts from Empa are in charge of its operational safety.

TEXT: Rainer Klose / PICTURES: Kuhn Group

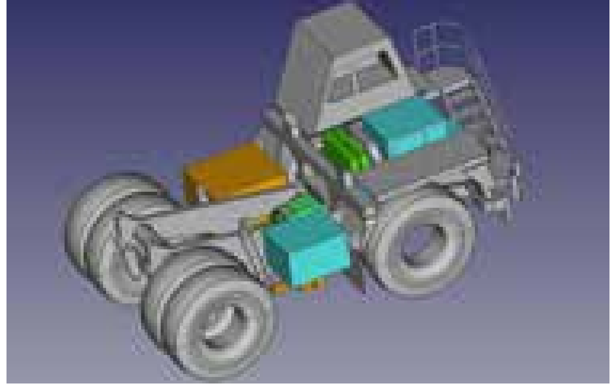
It will be the largest electric vehicle in the world: weighing in at 45 tons when empty plus 65 tons of loading capacity – and a battery pack boasting 700 kWh of storage capacity. That’s as much as eight Tesla Model S vehicles. The driver has to climb nine stairs to get to work and the e-mobile’s tires measure almost two meters in diameter. Not everything on the vehicle is new, however: the monster electric vehicle is based on a used Komatsu dumper truck, which is being disassembled and reconstructed at Kuhn Schweiz AG in Lommis. The diesel engine has already been removed and space is being made around the chassis for the battery packs, which are supposed to power the vehicle in the second half of its life.

Ten hard years in the quarry

Ten hard years of toil are in store for the electrically powered Komatsu HD 605-7. It is expected to transport material down from a mountain ridge and into the valley 20 times a day – more precisely, from a quarry on the slopes of the Chasseral to the Ciments Vigier SA cements works near Biel. The electric drive carries key advantages for these journeys: instead of heating up the brakes during the descent, the gigantic electric engine acts like a generator recharging the battery pack. The empty truck then uses this energy to travel back up the hill. If all goes as planned, the electric dumper truck will even harvest more electricity while traveling downhill than it needs for the ascent. Instead of consuming fossil fuels, it would then feed surplus electricity into the grid.

This seemingly barmy idea is costing Ciments Vigier SA a seven-digit sum (in Swiss francs). A team comprising two companies is to get the vehicle rolling: Lithium Storage GmbH from Illnau, which brings experience of electric trucks to the table, and the Kuhn Group, which sells Komatsu dumper trucks all over Europe. The Swiss Federal Office of Energy (SFOE) is supporting the project. Empa is also in on the action: battery expert Marcel Held is in charge of safety assessments. He is evaluating the battery pack produced by Chinese manufacturer Shenzen Westart and checking its giant construction and the programming of the battery management system, which stems from Swiss manufacturer Esoro.

Until last year, the Komatsu dumper truck chugged around the cement works quarry powered by its Diesel engine. In a few months, it will be expected to do the same job running purely on electricity.

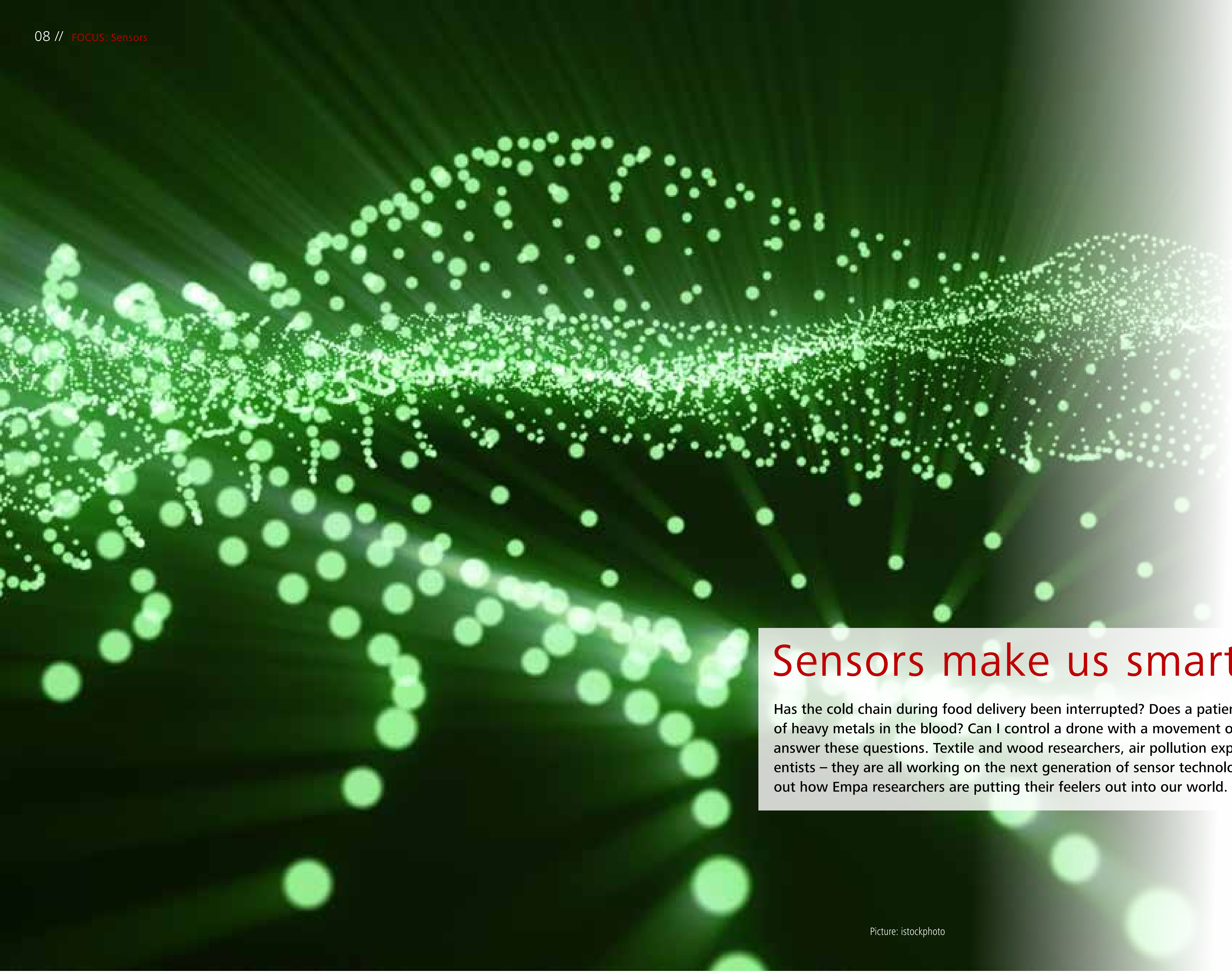


The diesel engine and the 700-liter tank are being revamped to make way for two battery packs (blue).

The cornerstones of the battery pack have already been fixed: the battery pack for the e-dumper will weigh 4.5 tons and consist of 1,440 nickel manganese cobalt cells.

Never before has a land vehicle been fitted with such a vast battery pack. “Nickel manganese cobalt cells are also the choice of the German automobile industry when it comes to the next generation of electric cars,” explains Held. He is primarily interested in how the cells respond if an accident occurs. What happens if a cell is damaged mechanically? If a switch malfunctions and the battery does not disconnect from the electricity once charged? “Some batteries start smoking, others burst into flames,” as Held is all too aware. “The crucial thing in this instance is to make sure the neighboring cells are not damaged by the fire and heat, otherwise there is the risk of a chain reaction.” Held will conduct overcharging tests at Empa’s test rig and also mistreat a few cells with a steel nail.

Never before has a vehicle of this performance class been constructed to conquer slopes of up to 13 percent inclination under the harshest of environmental conditions while straining the batteries with electrical currents of up to 3,000 amperes, but also charging them by 40 kWh during a single descent and traveling as an energy plus vehicle on balance (plus 10 kWh of energy per roundtrip). If the use of the new vehicle proves successful, Ciments Vigier SA could power up to eight vehicles purely electrically in the long run. For Kuhn Schweiz AG this opens up new fields for large-scale construction machines, such as in tunnel construction or in residential areas that are sensitive to exhaust gas and noise. //



Sensors make us smarter

Has the cold chain during food delivery been interrupted? Does a patient have harmful levels of heavy metals in the blood? Can I control a drone with a movement of my wrist? Empa helps answer these questions. Textile and wood researchers, air pollution experts and polymer scientists – they are all working on the next generation of sensor technology. Read on to find out how Empa researchers are putting their feelers out into our world.

Picture: istockphoto

The fruit spy

On the long journey from the fruit plantation to the retailer's shelf, fruits can quickly perish. In particular, the refrigeration inside the cargo containers is not always guaranteed and existing methods for measuring the temperature are not sufficiently reliable. A sensor developed at Empa solves this problem. It looks like a piece of fruit and acts like a piece of fruit.

1

2

3

1
The hull around each sensor has to reproduce the exact sugar and water level of the original fruit. There are models for Braeburn and Jonagold apples, the Kent mango, oranges and the classic Cavendish banana.

2
The previous method was flawed: the sensors were stuck into slices of (real) fruit. As soon as the fruit started to rot, however, the readings became distorted.

3
The sensor fruit accompanies the produce throughout the entire supply chain. The data only needs to be evaluated if something goes awry.

TEXT: Cornelia Zogg / PICTURES: Empa

Mangos, bananas and oranges have usually travelled long distances by the time they reach our shops. They are picked, packaged, refrigerated, packed in refrigerated containers, shipped, stored and finally laid out on display. However, not all the cargo makes it safely to its destination. Although fruit is inspected regularly, some of it is damaged or may even perish during the journey. This is because monitoring still has significant scope for improvement.

Although sensors measure the air temperature in the freight container, it is the core temperature of the individual fruit that is decisive for the quality of the fruit. However up to now, it has only been possible to measure this "invasively", i.e. by inserting a sensor through the skin and into the centre. And even this process has drawbacks. To carry out the measurement, the technician usually takes a piece of fruit from a cardboard box in the front row of pallets in the container, which in turn distorts the result. Fruit that is closer to the outside of the transport container is better refrigerated than fruit on the inside.

Sometimes whole container loads have to be destroyed because the temperatures on the inside of the container did not meet the prescribed guidelines. The USA and China, in particular, are extremely strict regarding the importation of fruit and vegetables. If the cargo has not been stored for three weeks at a certain minimum temperature, it is not authorised for sale in the country. Not only does refrigeration serve to maintain the freshness and quality of the fruit, it also kills any larvae, such as moth larvae, which can nest in the fruit. It is therefore essential to prove that the refrigeration has actually penetrated all the fruit in the whole consignment for the required period of time.

The sensor travels with the fruit

In order to guarantee and monitor the temperature within the fruit, researchers at Empa have now developed an artificial fruit sensor. It is the same shape and size as the relevant fruit and also simulates its composition, and can be packed in with the real fruit and travel with it. On arrival at the destination, data from the sensor can be analysed quickly and easily. From this, the researchers hope to gain information about the temperature during transportation.

This is important information, primarily for insurance reasons: if a delivery does not meet the quality requirements, the sensor can be used to establish the point in the storage and transport chain at which something went wrong. Initial results are certainly very promising: "We analysed the sensors in the Empa refrigeration chamber in detail and all the tests were successful," explains Project Manager Thijs Defraeye from the Laboratory for Multiscale Studies in Building Physics. Field tests are under way at Agroscope in Wädenswil.

An artificial fruit sensor for Braeburn and Jonagold apples

However, the same sensor does not work for all fruits, as Defraeye explains. "We are developing separate sensors for each type of fruit, and even for different varieties." There are currently separate sensors for the Braeburn and Jonagold apple varieties, the Kent mango, oranges and the classic Cavendish banana. In order to simulate the characteristics of the individual types of fruit, the fruit is X-rayed, and a computer algorithm creates the average shape and texture of the fruit. From the literature or based on their own measurements, the researchers then determine the exact composition of the fruit's flesh (usually a combination of water, air and sugar) and simulate this in exactly the same ratio in the laboratory, although not with the original ingredients, instead using a mixture of water, carbohydrates and polystyrene.

This mixture is used to fill the fruit-shaped sensor mould. The mould is produced on a 3D printer. The researchers place the actual sensor inside the artificial fruit, where it records the data, including the core temperature of the fruit. Existing measuring devices on container walls only provide the air temperature, but this is not sufficiently reliable because the fruit can still be too warm on the inside. Although such fruit core simulators already exist in the field of research, they are not yet sufficiently accurate, explains Defraeye. One such example that has been used is balls filled with water with a sensor inside. "We have conducted comparative tests," says the researcher. "And our filling provided much more accurate data and simulated the behaviour of a real piece of fruit much more reliably at different temperatures."

Not (yet) wireless

Initial field tests on the sensors are currently under way and the researchers are now looking for potential industrial partners to manufacture the fruit spies. The investment is certainly likely to be worthwhile. It is estimated that the cost of such a sensor is less than CHF 50. The data would only have to be analysed if something was wrong with the delivered goods. This would then make it possible to efficiently establish where in the process an error had occurred.

Another desirable feature would be to be able to receive the data from the cargo container live and in real time, so that appropriate countermeasures could be taken in the event of abnormal data – thereby potentially saving the fruit cargo. That would require a wireless or Bluetooth connection. "However, our current fruit sensor cannot do that yet. And the price of the product would, of course, go up," says Defraeye. But the profits for the companies would probably also go up if the fruit sensors enabled them to supply more goods in perfect condition. //

Biosensor for heavy metals

A team of Empa scientists has developed a biosensor which allows them to detect elevated concentrations of copper in a simple, quick and economic way. Copper, like other heavy metals, is problematic in high concentrations, both for the environment and for human health.

TEXT: Celine Elber / PICTURES: Empa

It is no secret that heavy metals such as copper are dangerous substances which can have grave consequences for both our environment and for human health. Liver damage, Alzheimer's disease and even cancer have all been associated with high levels of copper. Despite this, the concentration of heavy metals is often very high, both in the atmosphere and in water sources, particularly in some developing countries

In order to detect an excessive dose of heavy metals as early as possible, and thereby avoid the resulting health problems, highly sensitive analyses of samples such as blood are essential. However these tests are often expensive and time-consuming, requiring an appropriate level of laboratory infrastructure. In developing countries – where exposure to heavy metals at its highest – this often represents a problem.

A protein with a weakness for copper

Empa doctoral student Ramon Weishaupt has studied a more economic and faster way of measuring copper concentrations. To do this he combined a red fluorescing protein called c-phycocyanin (which plays a role in the photosynthesis of cyanobacteria and binds to copper ions even at very low concentrations) with a nano-cellulose matrix to create a thin film. When copper ions bind to the bacterial protein the fluorescent emission becomes weaker, and this change can be quickly and easily measured with a spectrometer.

The base material, micro-fibrillated cellulose, also stems from Empa's labs: the highly versatile fibrous material made of renewable raw materials was developed at the Laboratory for Applied Wood Materials.

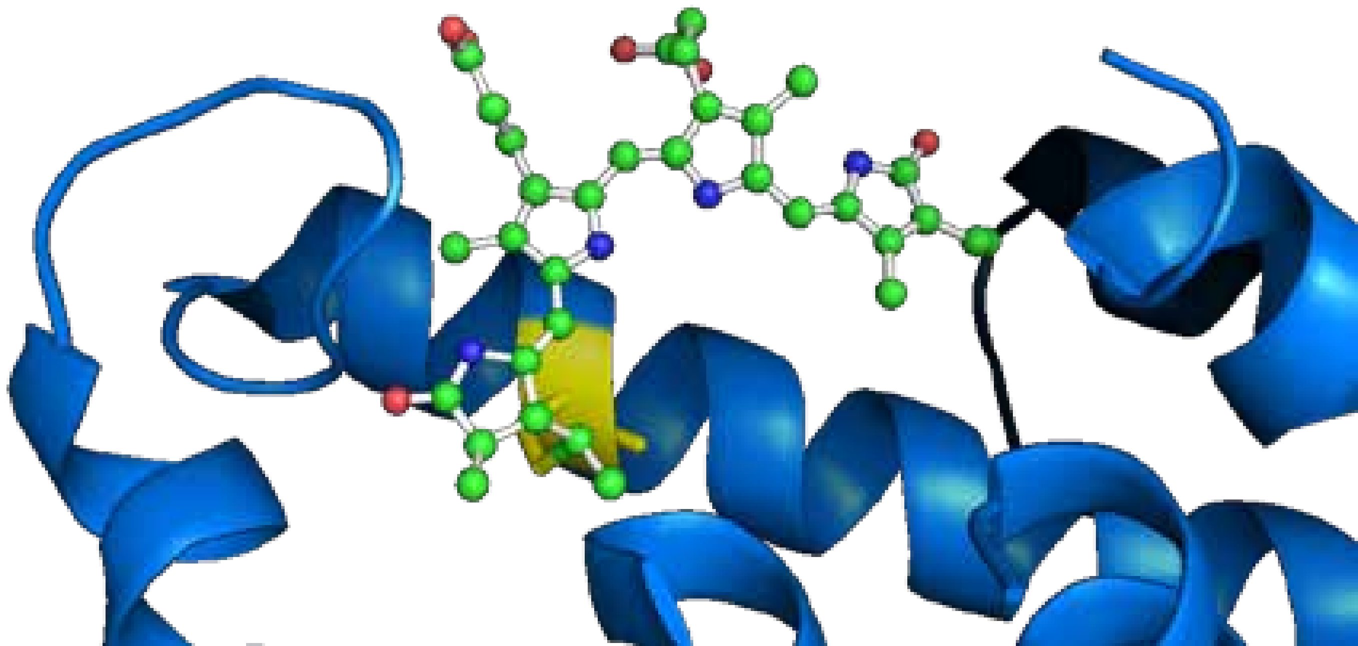
The researchers have tested the new technology, which they have named Cy Sense, on blood samples, among others. "One drop of blood is sufficient for the method to detect a concentration of copper relevant to human health" explains, Greta Faccio, Empa scientist. CySense can be economically produced, is easy to use and is quick and accurate. In addition, if the biosensor is washed clean with special chemicals and water, it can be used again and again over a one-week period.

As simple as measuring blood sugar

The team's findings, which are presented in a paper published in the scientific journal "Advanced Functional Materials", open new avenues in the field of heavy metal analysis. Water and soil samples can be evaluated on the spot, for example, saving both cost and time. Or affected users could monitor copper levels in their own blood, using the CySense technique and a reading device similar to a blood sugar monitor, thus obviating the need for large, expensive instruments and highly trained personnel. "Although Cy Sense is still a prototype, once it has been implemented as a marketable system it could help to improve the health of a large number of people", predicts Greta Faccio. //

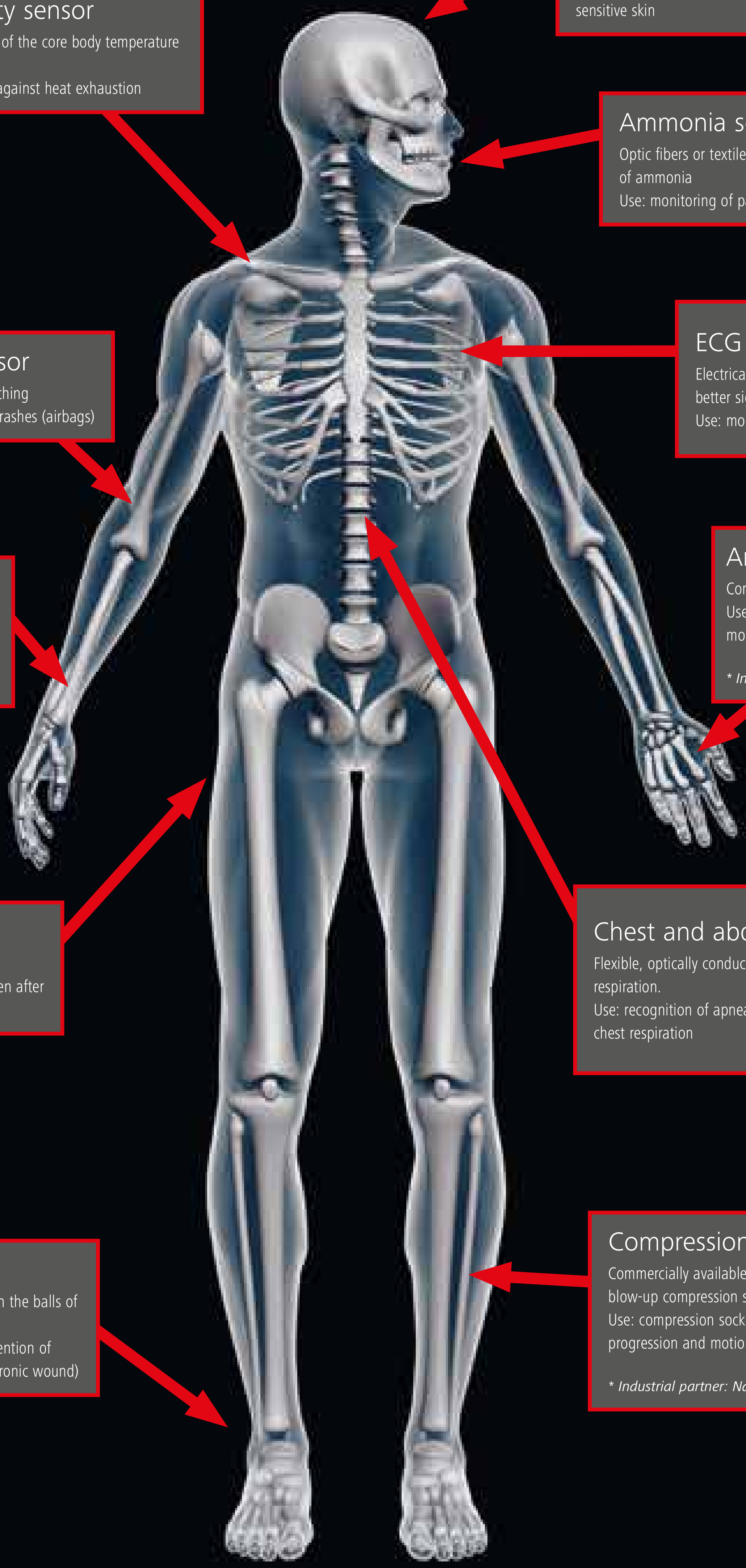
left:
Ramon Weishaupt during a series of tests using blood serum.

right:
C-phycocyanin, a red-glowing protein, helps detect copper ions. One drop of blood is enough for the analysis.



Non-invasive textile sensors

Many body functions and even disease symptoms can be detected and treated accurately with sensors. Empa specializes in high-precision textile sensors that monitor larger areas of the human body. The Empa sensors are based on optically and electrically conductive fibers and need to lie directly on the skin.



Temperature and humidity sensor

Measures large areas of the skin. Calculation of the core body temperature based on physiologic models
Use: protective jackets that warn firefighters against heat exhaustion

Sensor cap with optic fibers

Measures oxygen saturation in the blood, skin circulation and heart rate
Use: monitoring premature babies, paraplegics and other patients with sensitive skin

Ammonia sensor for breath analysis

Optic fibers or textiles with a special coating. Recognizes traces of ammonia
Use: monitoring of patients with stomach infections or kidney disorders

Acceleration and position sensor

Commercially available sensors combined in smart clothing
Use: thermal comfort for motorcyclists, safety during crashes (airbags)

ECG chest belt

Electrically conductive fibers with moisture reservoir for a better signal transmission
Use: monitoring cardiovascular function. Long-term ECG

Smart wound dressing

Fluorescent dyes measure pH level and glucose concentration of a wound over larger areas
Use: inexpensive monitoring of chronic wounds in diabetics or patients with bedsores (see p. 18)

Anti-tremor glove

Commercially available motion sensors, blow-up fixator*
Use: Parkinson's patients. Glove recognizes muscle tremors and automatically stabilizes the wrist

** Industrial partner: Nahtlos GmbH, St.Gallen*

Cushions, air structures

Adaptive, blow-up cushions, sensor-controlled
Use: pain relief for hemorrhoids, support for women after an episiotomy

Chest and abdominal respiration sensor

Flexible, optically conductive fiber measures chest and abdominal respiration.
Use: recognition of apnea – if abdominal respiration is not in sync with chest respiration

Pressure sensor

Optic fiber, measures the pressure exerted on the balls of the feet / buttocks
Use: rehabilitation after sports injuries, prevention of bedsore in paraplegics and diabetic foot (chronic wound)

Compression socks

Commercially available position and motion sensors, blow-up compression socks*
Use: compression socks adapt automatically to disease progression and motion patterns

** Industrial partner: Nahtlos GmbH, St.Gallen*

image: istockphoto

Magic off the cuff

Moving things with a wave of the hand: thanks to Empa technology this dream could soon become real. A sensor made of piezo-resistive fibers integrated in a wristband measures wrist movements and converts them into electrical signals. This can be used to steer drones or other electronic devices without a remote control.

TEXT: Cornelia Zogg / PICTURES: Empa

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The watchstrap contains piezo-resistive fibers produced on a 3D printer. The wrist movements are transmitted to steer the drone.

A wave to the left: the drone moves to the left. A wave to the right: the drone turns right. Clench your hand into a fist and it lands gently on the table. No, not crazy talk; reality. Empa researchers headed by Frank Clemens from the Laboratory for High-Performance Ceramics have devised a sensor made of piezo-resistive fibers and incorporated it into a wristband that registers the hand's movements. The piezo-resistive fiber is electroconductive, recognizes a change in shape and converts it into an electrical signal, which can then be read by a terminal device and interpreted accordingly. This means that robots can be moved with a simple point of the finger, for instance.

Although motion sensors are nothing new, until now movements were primarily recorded using visual sensors (such as cameras), accelerometers and gyroscopes (for rotational movements). This manner of registering movements, however, requires large, clear movements within a particular speed range that are, by and large, unnatural for humans. The new Empa sensor, on the other hand, responds to the minutest of natural movements made "off the cuff". Nonetheless, Clemens doesn't want to do away with previous technologies. "It takes a combination of different sensors to develop new concepts. Only then can we spot and use movements that weren't detectable with previous technologies." Combining acceleration, rotation and orientation sensors with the new fiber sensor would facilitate completely new "commands" to control technical devices – whether it be a drone or the garage door.

Algorithms "translate" movements

For test purposes, the researchers integrated the sensor in a conventional wristwatch strap, which can be worn unobtrusively and restricts the wearer as little as possible. Run-of-the-mill decorative bracelets are also conceivable. Nevertheless, it took quite a while to reach this stage. In the first prototypes, Frank Clemens and Mark Melnykowycz succeeded in attaching the piezo-resistive fibers to a piece of fabric. This was insufficient to use the sensor on the desired scale, however. "With the aid of additive manufacturing, we managed to integrate the sensor structure in non-textile materials," explains Clemens. The sensor could thus eventually be used in existing wristwatch straps.

In collaboration with the companies STBL Medical Research AG and Idezo, Clemens's team then programmed the sensor in such a way that it could be used to control a drone with mere hand movements. Currently, the algorithm that "translates" between sensor and drone control is being optimized as part of a Bachelor's project at Bern University of Applied Sciences supervised by Marx Stampfli so that it can respond to even simpler gestures. Not only is the sensor supposed to recognize individual movements, but also entire movement sequences. For example, clenching your fist twice in quick succession would trigger a different command to once short and once long, and so on.

Wearing the sensor in a wristband might soon be a thing of the past, too. In her term paper, a student at ETH Zurich is examining the possibility of integrating the piezo-resistive sensor in a plaster. Then all that would be needed to perform diverse interactions with technical devices and robots would be a barely conspicuous plaster on the wrist. Although the project is still very much in its infancy, everything already works perfectly. "Together with our industry partner STBL Medical Research AG, we are currently discussing a potential industrial implementation with partners from various sectors," says Clemens. //

Piezo-electric sensor fibers from 3D printers – without any lead

Besides piezo-resistive sensors (see main text) Empa's Laboratory for High-Performance Ceramics is also developing piezo-electric sensors. Piezo-electric materials have become an integral part of our everyday lives. They are primarily required for sensors that make our lives easier, such as the park assist systems in our cars. A sound wave is emitted and the waves reflected are recorded and evaluated by a piezo-electric sensor. In contrast to piezo-resistive fibers, where only the resistance is altered, in piezo-electric sensors an electric voltage is generated. Empa researchers have now developed piezo-electric structures made of ceramics that can be printed on a conventional 3D printer. The ceramic 3D print enables completely different, novel structures for the sensors than was previously possible. However, the material is also being refined: previous piezo-electric sensors contained lead, which is virtually prohibited these days. The EU, for instance, has decided to switch to unleaded alternatives in future – but these are still under development. Empa's piezo-electric sensors make do without lead and could replace leaded sensors in various fields of applications one day..

Using a UV lamp, the pH level in the wound can be verified without removing the bandage and the healing process can continue unimpeded.

Bandage with a voice

A novel bandage alerts the nursing staff as soon as a wound starts healing badly. Sensors incorporated into the base material glow with a different intensity if the wound's pH level changes. This way even chronic wounds could be monitored at home.

TEXT: Martina Peter / PICTURE: Empa

All too often, changing bandages is extremely unpleasant, even for smaller, everyday injuries. It stings and pulls, and sometimes a scab will even start bleeding again. And so we prefer to wait until the bandage drops off by itself.

It's a different story with chronic wounds, though: normally, the nursing staff has to change the dressing regularly – not just for reasons of hygiene, but also to examine the wound, take swabs and clean it. Not only does this irritate the skin unnecessarily; bacteria can also get in, the risk of infection soars. It would be much better to leave the bandage on for longer and have the nursing staff "read" the condition of the wound from outside.

The idea of being able to see through a wound dressing gave rise to the project Flusitex (Fluorescence sensing integrated into medical textiles), which is being funded by the Swiss initiative Nano-Tera. Researchers from Empa teamed up with ETH Zurich, Centre Suisse d'Electronique et de Microtechnique (CSEM) and University Hospital Zurich to develop a high-tech system that is supposed to supply the nursing staff with relevant data about the condition of a wound. As Luciano Boesel from Empa's Laboratory for Biomimetic Membranes and Textiles, who is coordinating the project at Empa, explains: "The idea of a smart wound dressing with integrated sensors is to provide continuous information on the state of the healing process without the bandages having to be changed any more frequently than necessary." This would mean a gentler treatment for patients, less work for the nursing staff and, therefore, lower costs: globally, around 17 billion $ were spent on treating wounds last year.

When wounds heal, the body produces specific substances in a complex sequence of biochemical processes, which leads to a significant variation in a number of metabolic parameters. For instance, the amount of glucose and oxygen rises and falls depending on the phase of the healing process; likewise does the pH level change. All these variations can be detected with specialized sensors. With this in mind, Empa teamed up with project partner CSEM to develop a portable, cheap and easy-to-use device for measuring fluorescence that is capable of monitoring several parameters at once. It should enable nursing staff to keep tabs on the pH as well as on glucose and oxygen levels while the wound heals. If these change, conclusions about other key biochemical processes involved in wound healing can be drawn.

A high pH signals chronic wounds

The pH level is particularly useful for chronic wounds. If the wound heals normally, the pH rises to 8 before falling to 5 or 6. If a wound fails to close and becomes chronic, however, the pH level fluctuates between 7 and 8. Therefore, it would be helpful if a signal on the bandage could inform the nursing staff that the wound pH is permanently high. If the bandage does not need changing for reasons of hygiene and pH levels are low, on the other hand, they could afford to wait. But how do the sensors work? The idea: if certain substances appear in the wound fluid, "customized" fluorescent sensor molecules respond with a physical signal. They start glowing and some even change color in the visible or ultra-violet (UV) range. Thanks to a color scale, weaker and stronger changes in color can be detected and the quantity of the emitted substance be deduced.

Empa chemist Guido Panzarasa from the Laboratory for Biomimetic Membranes and Textiles vividly demonstrates how a sample containing sensor molecules begins

>>

Guido Panzarasa evaluating the results with a colleague

to fluoresce in the lab. He carefully drips a solution with a pH level of 7.5 into a dish. Under a UV light, the change is plain to see. He adds another solution and the luminescence fades. A glance at the little bottle confirms it: the pH level of the second solution is lower.

Luminous molecules under UV

The Empa team designed a molecule composed of benzalkonium chloride and pyranine. While benzalkonium chloride is a substance also used for conventional medical soap to combat bacteria, fungi and other microorganisms, pyranine is a dye found in highlighters that glows under UV light. "This biomarker works really well," says Panzarasa; "especially at pH levels between 5.5 and 7.5. The colors can be visualized with simple UV lamps available in electronics stores." The Empa team recently published their results in the journal "Sensors and Actuators".

The designer molecule has another advantage: thanks to the benzalkonium chloride, it has an antimicrobial effect, as researchers from Empa's Laboratory for Biointerfaces confirmed for the bacteria strain *Staphylococcus aureus*. Unwelcome bacteria might potentially also be combatted by selecting the right bandage material in future. As further investigations, such as on the chemical's compatibility with cells and tissues, are currently lacking, however, the researchers do not yet know how their sensor works in a complex wound.

Keen interest from industry

In order to illustrate what a smart wound dressing might actually look like in future, Boesel places a prototype on the lab bench. "You don't have to cover the entire surface of wound dressings with sensors," he explains. "It's enough for a few small areas to be impregnated with the pyranine benzalkonium molecules and integrated into the base material. This means the industrial wound dressings won't be much pricier than they are now – only up to 20% more expensive." Empa scientists are currently working on this in the follow-up project FlusiTex-Gateway in cooperation with industrial partners Flawa, Schöller, Kenzen and Theranoptics.

Panzarasa now drips various liquids with different pH levels onto all the little cylinders on the wound pad prototype. Sure enough, the lighter and darker dots are also clearly discernible as soon as the UV lamp is switched on. They are even visible to the naked eye and glow in bright yellow if liquids with a high pH come into contact with the sensor. The scientists are convinced: since the pH level is so easy to read and provides precise information about the acidic or alkaline state of the sample, this kind of wound dressing is just the ticket as a diagnostic tool. Using the fluorescence meter developed by CSEM, more accurate, quantitative measurements of the pH level can be accomplished for medical purposes.

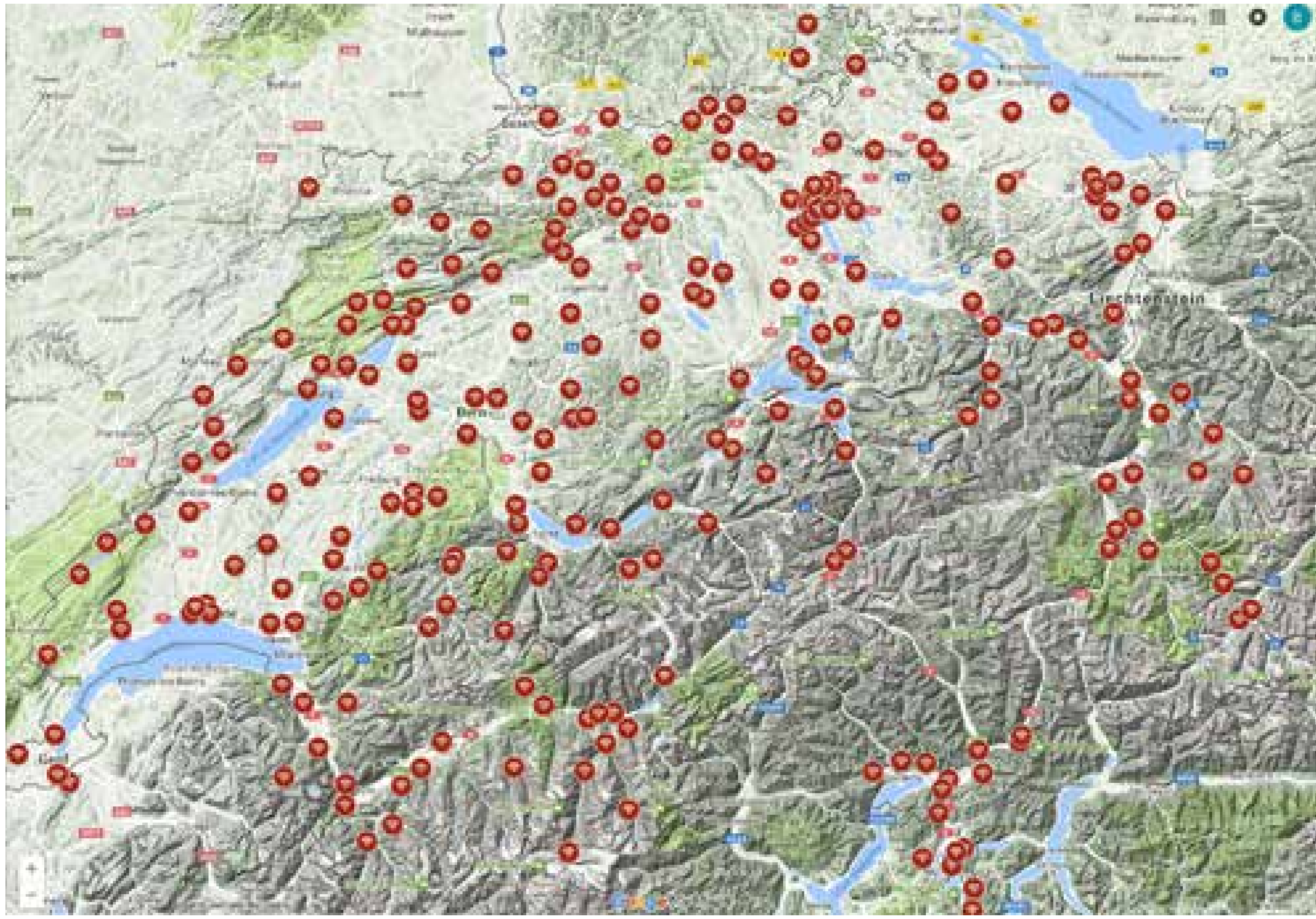
According to Boesel, it might one day even be possible to read the signals with the aid of a smartphone camera. Combined with a simple app, nursing staff and doctors would have a tool that enables them to easily and conveniently read the wound status "from outside", even without a UV lamp. And patients would then also have the possibility of detecting the early onset of a chronic wound at home. //

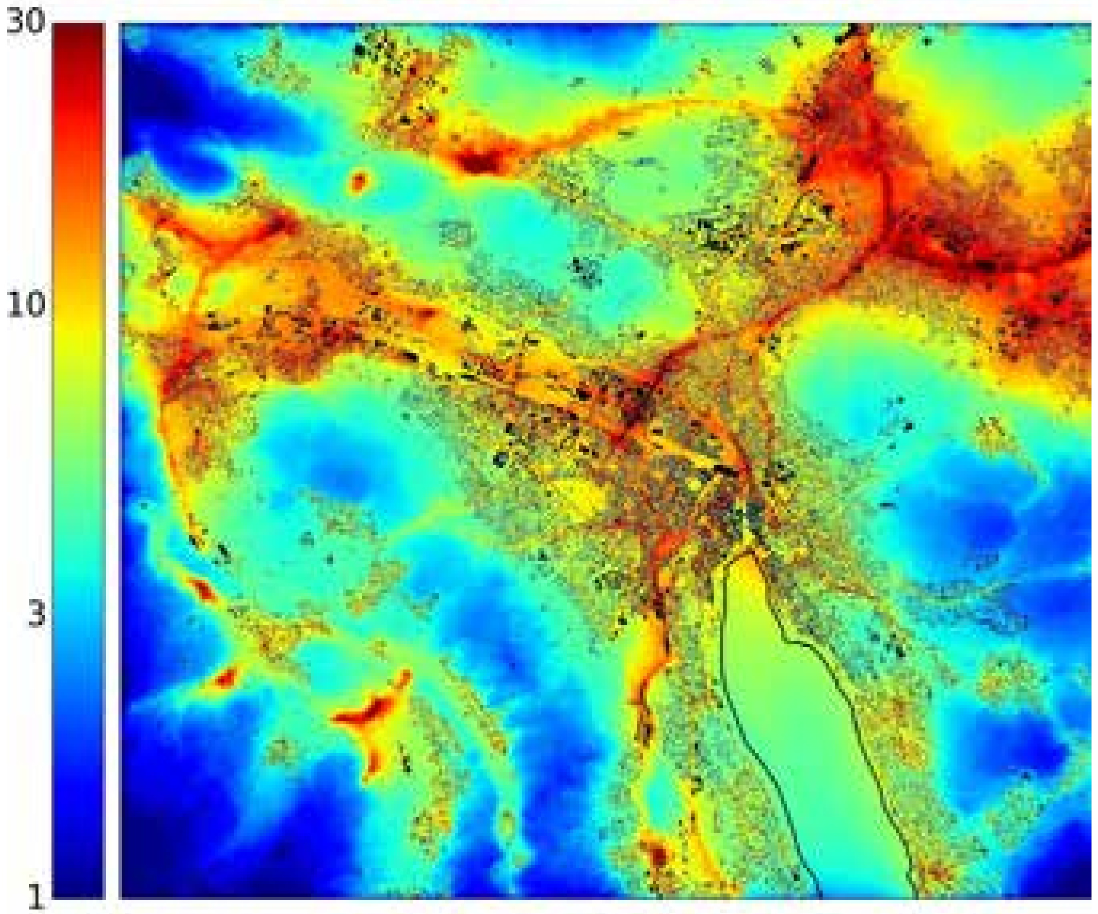
CO_2 under surveillance

Switzerland is to gain a dense, globally unique CO2 measuring network: 300 sensors permanently collect up-to-date readings, which form the basis for atmospheric dispersion models that are being developed at Empa.

TEXT: Martina Peter, Michael Lieberherr / PICTURES: Empa / Google Maps

In future, the CO_2 sensor network will collect data at 300 locations througHout Switzerland.





The distribution of the CO_2 concentration in the City of Zurich averaged over 2013 and 2014. Thanks to the readings from the sensor network, this kind of model calculation will be more precise in future.

With the Paris Agreement in 2015, the international community made a commitment to reduce global greenhouse gas emissions. Meanwhile (and despite the recent US pull-out by "El Donaldo"), over 190 nations have ratified the agreement. Individual cities have set themselves even more ambitious targets. What is currently lacking, though, are the right tools to measure progress – such as one that enables up-to-the-minute measurements of CO_2 levels.

The Carbosense project is creating new possibilities in this respect. Soon, 300 CO_2 sensors scattered all over Switzerland will be in use to convey their data in real time via the Internet of Things. So far, there were only a handful of places throughout the country for measuring CO_2 . This new dense, globally unique sensor network records spatial and temporal changes in CO_2 levels in the atmosphere. As project leader Lukas Emmenegger, head of Empa's Laboratory for Air Pollution/Environmental Technology, explains: "The CO_2 sensor network will be a valuable springboard that will allow us to better understand the natural and manmade sources and drains of CO_2 in Switzerland."

The x-ray machine for CO_2

For the City of Zurich, where the sensor network will be particularly close-knit, Empa developed a computer model that simulates the CO_2 concentration from ten different sources (see diagram). These emission sources include various kinds of traffic, industry or heating systems in residential buildings, for instance. By combining these simulations with the sensor data, Empa will be able to display the city's current CO_2 emissions practically in real time. "This will give us readings with a sufficient density to follow Zurich's CO_2 emissions virtually live," says Emmenegger. "What's more, the measurements will provide valuable information on the spread of other air pollutants."

The scientific and technical applications based on this sensor data recorded all over Switzerland, on the other hand, will give valuable hints for traffic planning, healthcare measures, developments linked to "smart cities", and even for a better understanding of the exchange of CO_2 between the atmosphere and the vegetation.

Swisscom is installing the CO_2 sensors at antenna sites. The 300 battery-powered sensors transmit their readings to the computing centers at the ETH Domain's Swiss Data Science Center (SDSC) via Swisscom's Low Power Network, which offers a narrow bandwidth but has a long range, transmits in an energy-saving manner and reduces network costs. This makes it just the ticket for linking up environmental sensors, parking spaces, containers or any other communal infrastructure.

Not only does science stand to benefit from the sensor network, but also the Low Power Network itself: the sensors scattered across the country are a good way to continuously assess network quality. Carbosense, a collaboration between Empa, SDSC, the Empa spin-off Decentlab and Swisscom, was initiated by Empa and Swisscom and is co-funded by nano-tera.ch. //

The Empa spin-off Decentlab

300 measuring devices scattered across Switzerland form the backbone of a CO_2 sensor network. Empa spin-off Decentlab integrated CO_2, temperature and moisture sensors along with a communication module for LoRaWAN (Long Range Wide Area Network) in a device and caters for the wireless, low-energy mediation of the data to the next gateway. These gateways are connected via the internet to Decentlab's cloud and visualization infrastructure. Empa scientists can access the data directly and are currently evaluating the data: depending on the time of day, the CO_2 values measured can be distorted by temperature and moisture. Thanks to new mathematical sensor models, however, these deviations can be corrected and losses of individual data packets can be "bridged".

Video (German language)
«CO_2-Messnetz in SRF-Tagesschau, February 6th, 2017
https://goo.gl/o2QyFJ

This new dense, globally unique sensor network records spatial and temporal changes in CO_2 levels in the atmosphere as well as moisture and tempeature. All data are accessible from a web platform.

Fertility app for parents-to-be

Since January 2017 a sensor wristband that, according to the manufacturer, is capable of detecting a woman's fertile days in her cycle with 89 percent certainty has been on the market. Empa helped developing the sensor technology.

TEXT: Rainer Klose / PICTURE: Ava AG

When is the right moment to get pregnant? A tricky question for couples who wish to have children. For many, using the temperature or rhythm method to pinpoint the fertile days is too inaccurate; other methods require lab tests and are thus inconvenient.

The medtech start-up Ava is now looking to answer this question with a state-of-the-art sensor wristband, which is worn at night and registers nine physiological parameters in the woman's calm sleep cycles: resting heart rate, skin temperature, heart rate variability, sleep, breathing rate, movement patterns, circulation, bio-impedance and heat loss from the skin. In the morning, the data is synchronized with a smartphone app, which calculates the increase in the sexual hormones estradiol and progesterone.

The Ava wristband is able to display 5.3 fertile days per month with an accuracy of 89 percent, as the manufacturer writes in a press release citing a study conducted at the University Hospital in Zurich. The device has been on the market in the US since the fall of 2016 and in Switzerland since January 2017.

It all began in the fall of 2014 with an Empa research project funded by the Commission for Technology and Innovation (CTI). As Empa researcher Simon Annaheim from the Laboratory for Biomimetic Membranes and Textiles recalls: "The aim was to determine a woman's hormonal status as accurately as possible using non-invasive methods." Annaheim began with conventional smartwatches and monitoring shirts, which were fitted with various sensors to gage body temperature, heart rate, acceleration, movement and body position, for example. The next step for the Empa team was to develop prototypes of the Ava wristbands and test them on volunteers.

Difficult measurements

It soon became clear just how difficult it is to measure the temperature with a wristband worn at night. The readings need to be accurate to within a tenth of the degree to provide reliable information about the hormonal cycle. However, the behavior of the test subjects caused far greater deviations. Alcohol consumption, a sunbath in the afternoon or a jog in the evening, for instance, triggered a much more significant increase in body temperature. The position of the hand with the wristband – under or on top of the blankets – also influenced the readings.

The solution: the researchers used two temperature sensors, one for the wristband's surroundings and one for the skin. Moreover, the measurements were postponed from the early sleep phases to the middle of the night as this is when all the bodily functions are more balanced and the readings become more stable. "The most important thing, though: we have to correlate the skin temperature with the series of other physiological parameters," says Annaheim. "Only then can we draw accurate conclusions about the cycle." The software that compares the readings was developed at the Centre Suisse d'Electronique et de Microtechnique (CSEM) in Neuchatel.

The Ava wristband is worn at night and records the necessary data mainly in the second half of the night.

In the morning, the user synchronizes the data with a smartphone app – and receives the calculation of her fertile days.

Empa's research activities soon bore fruit: the project was completed in December 2015 and by the summer of 2016 the wristband had reached the market in the US. According to a press release over 50 pregnancies have already been confirmed among wearers of the wristband.

"Empa was one of Ava's first research partners and instrumental in the development of the basic concept. We're delighted to underscore this with joint publications," says Peter Stein, VP R&D at Ava. //

A rubber power station

Researchers from Empa have developed a flexible material that generates electricity when stressed. In future, it might be used as a sensor, integrated into clothing or even implanted in the human body, for instance, to power a pacemaker.

TEXT: Celine Elber / PICTURES: Empa, Wikipedia

Flexible, organic, thin – properties that aren't usually associated with power plants or sensors. But a new material developed by Empa researchers is exactly that: a thin, organic, flexible film that generates electricity if stretched and compressed again. A kind of rubber, this film could be incorporated into control buttons, clothing, robots or even people, and monitor activities, record touches or generate electricity when stressed to power implanted devices such as pacemakers, for example.

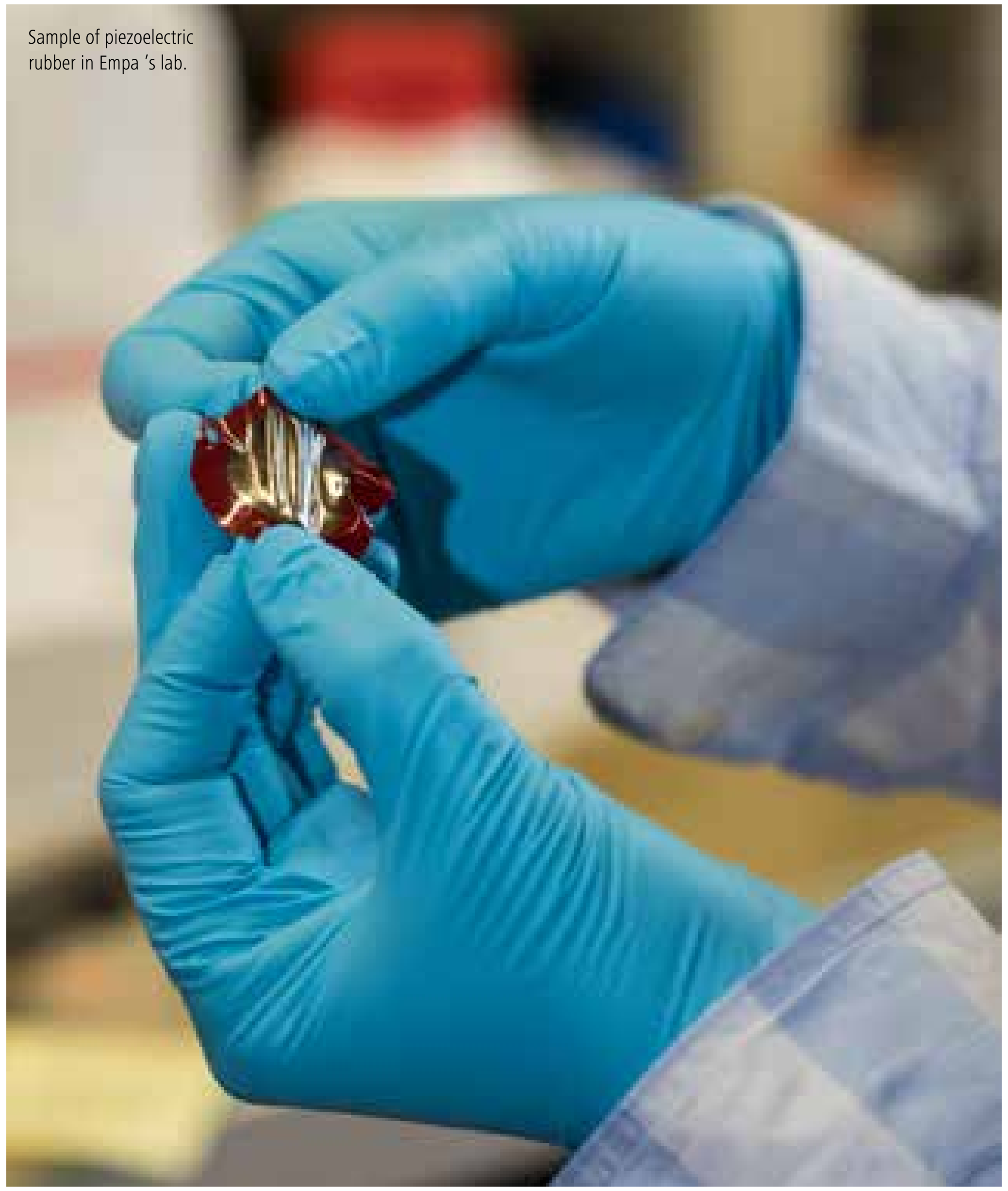
Turning motion into electricity

Thanks to the piezoelectric effect, the rubber is able to convert mechanical movements into electrical charges. The trick behind the technique is straightforward: in piezoelectric materials, the positive and negative charge centers overlap, the charges balance each other out and the material is electrically neutral on the surface. If the material is stressed or compressed, however, the material's inner structure is deformed and the charge centers shift in different directions generating an electrical voltage between the positive and negative charge centers.

This effect is used in sound pick-ups on analogue record players, for instance: the needle is guided through the grooves in the record in such a way as to generate mechanical vibrations. In a piezoelectric crystal, these vibrations are converted into electrical impulses, which in turn can be amplified and transformed into sound waves.

For a long time, the piezoelectric effect was only known for crystals. As these are heavy and solid, the effect could only be used in certain applications. However, Empa researcher Dorina Opris and her colleagues have now succeeded in giving elastomers piezoelectric properties. Nevertheless, the new material is not easy to produce. The rubber is a composite material made of polar nanoparticles and an elastomer (silicone in the prototype). First of all, Yee Song Ko, a PhD student at Empa, has to shape the two materials before connecting them. This yields a thin, elastic film, in which the polar moieties of the nanoparticles are still randomly oriented.

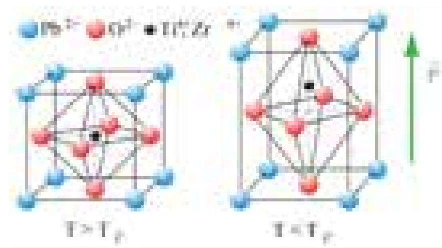
In order to create a piezoelectric material, Song Ko has to orient the polar moieties correctly via a strong electrical field. At the same time, the film is heated until the glass transition temperature of the nanoparticles has been exceeded and they change from a solid, glassy state into a rubbery, viscous one. Under these conditions, the polar moieties are guided by the electrical field. The orientation achieved is eventually frozen by cooling the material.



Sample of piezoelectric rubber in Empa 's lab.

Piezoelectric effect

The piezoelectric effect was discovered in crystals by brothers Jacques and Pierre Curie in 1880. While conducting experiments using tourmaline crystals, they found that electrical charges were produced during mechanical deformation on the surface of the crystals. This is due to dipoles in the crystal structure resulting from the deformation. The first applications were piezoelectric ultrasonic transducers and crystal oscillators for frequency stabilization. This gave rise to the first quartz clock at the Bell Laboratories in the US in 1928. Industrially manufactured piezo-ceramics often comprise lead zirconium titanate (PZT); see diagram.



Body parts as a power plant

There is a wealth of potential applications for the novel rubber film. It could be used to construct pressure sensors, for example. If the material is compressed, an electrical impulse is produced that can be received and "understood" by devices. This can be used to develop a novel type of control buttons, but also a sensitive skin for robots that can feel (pressure) touches. Moreover, the film might be useful in clothing to either monitor the wearer's activities or generate electricity from their movements. "This material could probably even be used to obtain energy from the human body," says Opris. "You could implant it near the heart to generate electricity from the heartbeat, for instance." This could power pacemakers or other implanted devices, eliminating the need for invasive operations to change the battery.

3D printer inks from the woods

Gilberto de Freitas Siqueira and Tanja Zimmermann from the Laboratory for Applied Wood Materials have succeeded in developing an environmentally friendly 3D printing ink made of cellulose nanocrystals in collaboration with researchers at Harvard University and ETH Zurich. This can be used to manufacture microstructures with outstanding mechanical properties. "The biggest challenge was to achieve a viscous elastic consistency that could also be squeezed through the 3D printer nozzles," says Siqueira. Cellulose is the most common natural polymer on Earth and is found in trees, plants and even bacteria. Not only can the novel ink be used for the automobile or packaging industry, but also in biomedicine, such as for implants or prosthetics.

100 guests listen to laser experts

More than 100 guests from industry and politics convened at Empa's Thun campus to experience Empa's laser expertise at first hand. The info event "Lasers – the Perfect Tool" constitutes an initial step towards establishing a competence center where additional production methods using lasers are investigated and developed. Besides established laser removal processes such as cutting, drilling and milling, joining techniques such as welding or 3D laser printing are also becoming increasingly interesting for manufacturers of precision parts. Collaborations with companies from Central and Western Switzerland are on the cards. The future Competence Center for Additive Manufacturing in Thun is being established with funding from the Canton of Bern and the City of Thun.

Tage der Technik

Fabrik der Zukunft – Herausforderung für Mensch und Technik

Hauptveranstaltung am Mittwoch, 4. Oktober 2017
Empa, Dübendorf, AKADEMIE

Wir stehen heute mitten in der vierten industriellen Revolution. Der Kern – auch als Industrie 4.0 bekannt – ist die durchgehende Digitalisierung und Vernetzung der Wertschöpfungsprozesse. Die «intelligente» Fabrik erlaubt eine individualisierte, flexible und maximal effiziente Fertigung.
Alle Produktionseinheiten sollen miteinander kommunizieren und sich auch selbst organisieren. Additive Herstellungsverfahren ermöglichen neuartige technische Produktionsformen.

Wie sich diese Transformation konkret auswirken wird, darüber wird heute viel diskutiert und spekuliert. Nur eines ist sicher: Veränderungen kommen auf uns alle zu. Industrie, Wirtschaft, Bildung und Gesellschaft werden nachhaltig geprägt werden und müssen sich damit auseinandersetzen. Industrie 4.0 ist deshalb nicht nur als Vision zu verstehen, sondern auch als eine Aufforderung zum Handeln

Die Tage der Technik 2017 greifen diese vielschichtige Thematik auf und beleuchten sie aus den verschiedenen Blickwinkeln von Wissenschaft, Technik und Gesellschaft.

Die Veranstaltungen sind öffentlich, der Eintritt gratis. Anmeldung und Programm unter: **www.tage-der-technik.ch** (Anzahl der Plätze ist beschränkt).
Im Rahmen der Tage der Technik2017 finden auch weitere Partnerveranstaltungen statt, die über www.tage-der-technik.ch zu finden sind.

Organisation

SWISS ENGINEERING STV UTS ATS

Empa Materials Science and Technology

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Events (in German)

22. August 2017

Seminar: Innovative Baustoffe
Zielpublikum: Industrie und Wirtschaft
www.empa-akademie.ch/rfa
Empa, Dübendorf

24. August 2017

Innovation Day 2017
Textil- und Bekleidungsindustrie und Zulieferer
www.swisstextiles.ch
Empa, Dübendorf

27. - 31. August 2017

19th WMO / IAEA Meeting on CO_2, other Greenhouse Gases and Related Measurement Techniques
Zielpublikum: Forschende
www.empa-akademie.ch/ggmt2017
Empa, Dübendorf

11.- 12. September 2017

Alloys for Additive Manufacturing Symposium
Zielpublikum: Industrie und Wirtschaft
www.mpie.de/aams2017
Empa, Dübendorf

4. Oktober 2017

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