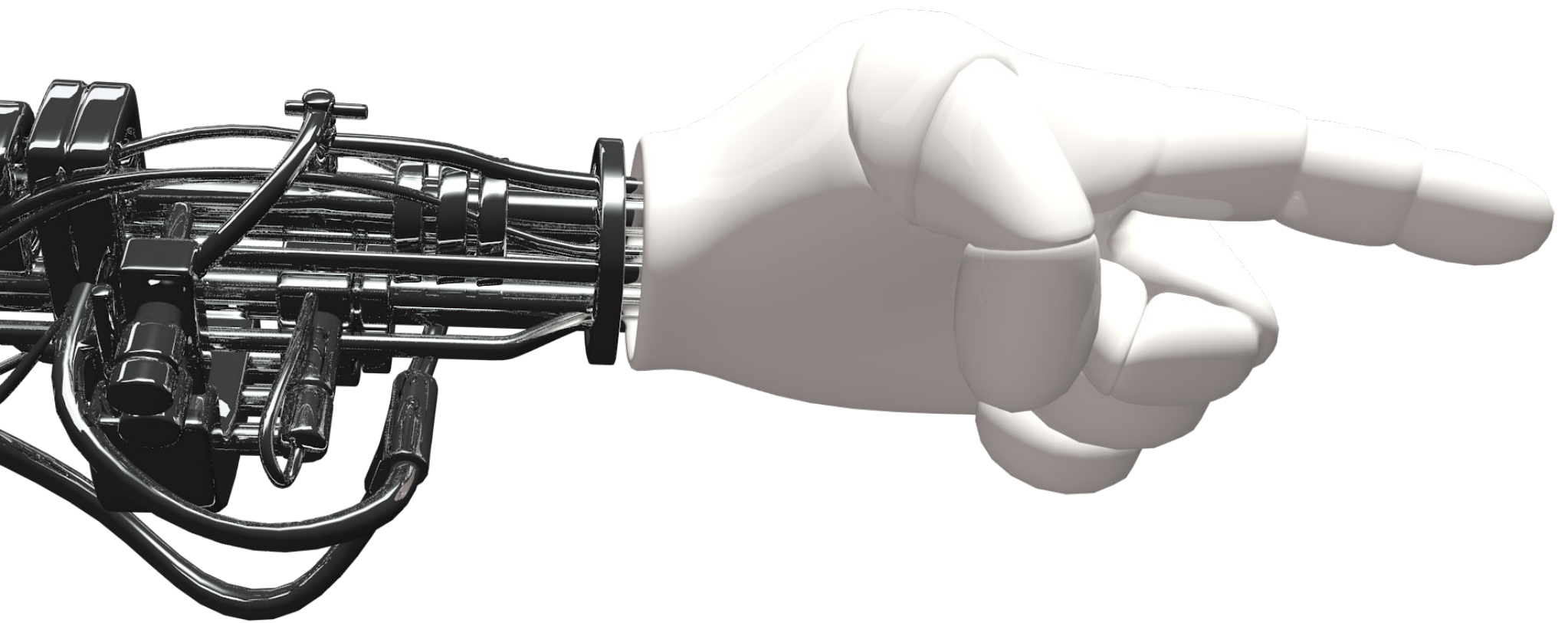


A FASTER, SMARTER FUTURE

Emerging Applications for 5G
and Edge Computing



INTRODUCTION

The difference between bits and atoms is blurring. Over the next decade, the network will become an overlay on top of our physical world. The virtual and real will blend in deeply immersive experiences that bring us closer together, no matter where we may be. The world will explain itself through augmented reality. As we imbue everyday objects with computer intelligence and communication capabilities, the Internet of Things will spring to life with myriad devices communicating with us, and each other. Pervasive sensor networks will open new vistas on our planet. Every object, every interaction, and every observation will become a piece of data to inform advanced simulations. Meanwhile, we'll soon be sharing our offices, hospitals, schools, roads, and homes with a new breed of companion: intelligent robots. Over the next decade, we'll see these intelligent machines in a different light and reconsider how we see ourselves.

These transformations will be driven by the proliferation of 5G networks and edge computing. The 5G networks on the horizon will be dramatically faster than today's wireless infrastructure, but they'll also break the barriers of network latency, the period between when your device requests data from the cloud and the network sends that data. As a result, the massive amount of near real-time data crunching necessary for your smartphone to render a convincing virtual world or for a robot to learn how to clean your house can be moved to the network. The model, called edge computing, essentially makes it possible for any connected device to have the power of a supercomputer.

"Edge computing fulfills the promise of the cloud to transcend the physical constraints of our mobile devices," says Andre Fuetsch, president of AT&T Labs and AT&T's chief technology officer. "The capabilities of tomorrow's 5G are the missing link that will make edge computing possible."

With that in mind, we present the following forecast of applications at the intersection of 5G and edge computing. (A prior AT&T Futurist Report titled "[Blended Reality](#)" specifically explored the future of entertainment.)

The emerging technologies of 5G and edge computing promise an unprecedented opportunity to augment and elevate the human experience. The rest is up to us.

About This Report

To create this latest installment in AT&T's Futurist Report series, "A Faster, Smarter Future: Emerging Applications for 5G and Edge Computing," AT&T collaborated with Institute for the Future (ITF), which drew from its ongoing deep research in mobile computing, wireless networking, and artificial intelligence, along with adjacent and intersecting areas, from human-computer collaboration to "the Internet of Actions." ITF then conducted interviews with experts in academia and industry for their divergent viewpoints. Informed by that research, ITF synthesized five big stories likely to play out over the next decade at the intersection of 5G networks and edge computing. Each of these big stories is supported by six "Signals," present-day examples that indicate directions of change. Think of a Signal as a signpost pointing toward the future.

AT&T and ITF hope that the foresight contained in this Futurist Report provokes insight that drives strategic action in the present.

LEARNING FLOWS

Education will take place in continuous and context-aware mobile learning channels blending digital and physical experiences.

High-speed mobile networks and artificial intelligence at the network's edge will draw education out of episodic experiences in classrooms and into learning flows coursing through our daily lives. We will engage in continuous learning channels that are always accessible through location-based augmented reality (AR) and virtual reality (VR) experiences that are relevant to where we are at the moment. Personal AIs will guide our "continual education," understanding our interests and needs to proactively reveal teachable moments that inspire, inform, and educate. Meanwhile, ultra-high-definition video streaming intersecting with low-latency, roaming telepresence robotics will dramatically expand the concept of "distant learning" as students remotely explore historical or scientific sites.

"With 5G, you can use AR and VR to learn at work, at home, from your commute, or anywhere else," says Maya Georgieva, Director of Digital Learning at The New School and co-founder of Digital Bodies. "And machine learning and AI can contextualize and personalize the information."

Imagine: Kindergartners at recess will develop a visceral understanding of physics through scientific explanations digitally superimposed on playground equipment. High schoolers in Tel Aviv can cap off an earth sciences unit by collaboratively controlling a telepresence robot inside an active volcano in Hawaii. A team of biology graduate students dispersed around the world will be able to simultaneously accompany scientists into the rain forests of Brazil via telepresence and then meet together in a virtual classroom to discuss their findings.

From remote apprenticeships and collaborative networks to content commons and algorithmic education, the networked learning economy will be integrated into the way we play and work. And perhaps most importantly, these learning experiences will be social, collaborative, and immersive to drive deep engagement.

"Every day can be a field trip," Georgieva says.

"The future of education technology is taking learning out of the pages of books and making it part of your world."

—MAYA GEORGIEVA, DIRECTOR OF DIGITAL LEARNING, THE NEW SCHOOL AND COFOUNDER, DIGITAL BODIES

Augmented Classroom

WHAT: Blippar's augmented reality creation tools Blippbuilder and Blippbuilder Script are easy drag-and-drop authoring tools for augmented reality that enable publication of the experiences to multiple mobile apps.

SO WHAT: The company has created a series of educational AR experiences for young students but encourages teachers and learners to “create your own augmented reality experiences to bring lessons to life.”



Museum of Other Realities

WHAT: Described as “a new space for a new kind of culture,” the Museum of Other Realities is a fully immersive virtual exhibition hall for artists to share their experimental digital creations with the public and each other.

SO WHAT: The MOR is an example of a social VR experience where a geographically disparate community can gather to interact and learn together.



Reading, Writing, and Robots

WHAT: Vecna Technologies' VGo is a mobile telerobot controllable that "enables a person to replicate themselves in a distant location and have the freedom to move around as if they were physically there."

SO WHAT: The company has made headlines for its efforts helping home- and hospital-bound students use the VGo robot to participate in the social classroom experience.



New Lens on History

WHAT: Launched by BBC Arts to complement a new TV series about human creativity, Civilisations AR is a mobile augmented reality app that delivers, for example, an X-ray view into an ancient Egyptian mummy from the Torquay Museum or a digital “eraser” to see how an artwork has faded over the centuries.

SO WHAT: According to the BBC, the AR app “allows people across the globe to discover these remarkable objects and explore them ‘out of the display case,’ no matter where they may live.”



Distance Learning Gets Social and Virtual

WHAT: Immersive VR Education develops tools for educators “to create their own content in virtual classrooms or virtual training environments.”

SO WHAT: The company’s Engage platform enables anyone to hold virtual classes in simulated environments where participants can interact with each other, 3-D objects, and other media content.



Immersive VR Education

Computer As Tutor

WHAT: The IBM Watson Tutor uses natural language processing and machine learning in the cloud to provide students with personalized educational support. It's based on the company's cloud-based AI service that famously beat two champions of the *Jeopardy!* TV quiz show.

SO WHAT: As the intelligent tutoring system gets to "know" the student and tracks progress, it adapts the conversation and content to meet the individual's learning style and needs.



DISTRIBUTED SCIENCE AND NETWORKED DISCOVERY

We will blanket the planet with devices that can see, hear, and sense once-inaccessible areas and hidden phenomena.

Scientists and conservationists will soon gain access to unprecedented rivers of environmental data flowing through 5G networks. Miniaturized, inexpensive, wirelessly connected flocks of mobile scientific instrumentation with integrated sensor systems will measure and monitor rain forest health, air and water quality, climatic trends, atmospheric and ocean temperatures, greenhouse gases, radioactivity, archaeological digs, meteor showers, animal migration, and more.

5G's low latency and massive real-time data-transfer capability, combined with AI and edge computing, will open new doors for telerobotic fieldwork, remote sensing for agriculture and conservation efforts, animal-migration patterns, climactic changes, ocean-current flow rates, and satellite monitoring to improve environmental, health, and disaster forecasting. Professional scientists will need as much public involvement as possible to find patterns and draw out insights from the massive amounts of raw data after first-cut machine-learning analysis at the network's edge.

For example, Safecast is a non-profit organization in Japan that has deployed hundreds of mobile radiation sensors that volunteers attach to their cars and drones to take measurements all over the world. Safecast has recorded over 100 million radiation readings, and the database is used by scientists all over the world. Each sensor costs about \$750, and much of that cost is for the onboard processing and power-management subsystems.

According to Safecast cofounder Sean Bonner, offloading the processing to an edge computing network environment and sending data over 5G could reduce the cost and power consumption of the Safecast devices. 5G will also make it easier and faster to broadcast firmware patches to hundreds or thousands of sensors in the field at once.

Today's scientists are distributed and networked; tomorrow, their tools will be as well.

“If 5G and edge computing is going to handle half of the processing and power management on a sensor, I don't have to worry about it anymore. I can have a smaller device that uses less power, that perhaps does more and becomes more useful, and now it's cheaper, so I can deploy more of them.”

—SEAN BONNER, DIRECTOR AND COFOUNDER, SAFECAST

Roving Wireless Sensors

WHAT: After the meltdown of the nuclear reactor in Fukushima, Japan, two hackerspaces in Tokyo and Los Angeles formed a partnership called Safecast to design, manufacture, and distribute mobile radiation monitors.

SO WHAT: 5G networks will give scientists new ways to monitor conditions around the world using high-speed wireless sensors.

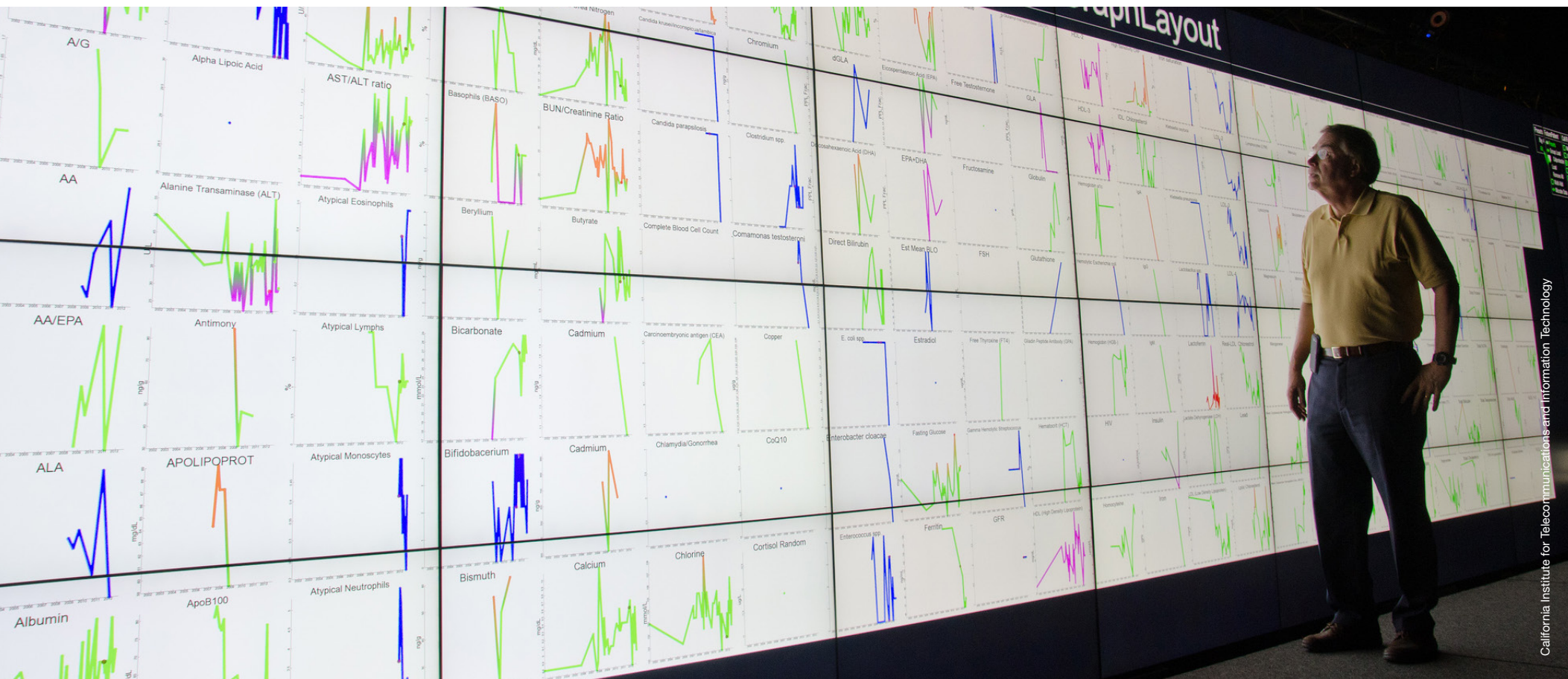


Science Data Gets a Backbone

WHAT: The Pacific Research Platform (PRP) is a high-speed network designed especially for data-intensive scientific research. Larry Smarr, principal investigator of the PRP and director of the California Institute for Telecommunications and Information Technology, says that the 5G network's optical

backbone will be an important part of PRP.

SO WHAT: "To accelerate the rate of scientific discovery, researchers must get the data they need where they need it and when they need it," said Smarr in a presentation about the PRP.



Sea Sensors

WHAT: Researchers from the Overturning in the Subpolar North Atlantic Program (OSNAP) deployed an array of undersea sensor probes across a large area of the Atlantic Ocean to better understand the currents in the North Atlantic.

SO WHAT: Susan Lozier, an oceanographer at Duke University

who leads OSNAP, told *Nature* that the changes in current strength surprised her team. “We always find more complexity and more variability, but perhaps that shouldn’t be surprising given how under-sampled the ocean is ... we just need to keep measuring.” 5G technology will give scientists new instruments for finer grain data collection.



Mathilde Jutras/Polarstern PS93-1 Cruise

Balloon-Borne Infrasound Sensors

WHAT: Scientists at Sandia National Laboratories developed solar-powered hot air balloons with GPS trackers and infrasound sensors to detect sources of low-frequency sounds, such as explosions and seismic activity, and triangulate on their source. Flying at three times the altitude of a commercial jet, the balloons

could potentially be used on other planets, like Venus and Jupiter.

SO WHAT: Sensors in the sky, on land, and in the oceans will give us a better understanding of our planet. High-speed, low-latency networks and edge computing will greatly increase the capabilities and possibilities of scientific-measurement projects.



Drone-Based Migration Monitor

WHAT: Researchers went to Western Canada and used drones and machine-vision software to better understand migration behavior of caribou by tracking individual animals as they moved.

SO WHAT: “This is a developing methodology that could be applied to many animal systems,” Santa Fe Institute fellow Andrew Berdahl, who co-led the expedition, told *National Geographic*. “I’d be tempted to say it will revolutionize studies of this kind.”



Paul Asman and Jill Lenoble (CC BY 2.0)

Pompeii Exploration Gets an Upgrade

WHAT: The ancient Roman city of Pompeii, which was buried by ash when Mount Vesuvius erupted in 79 A.D., is so remarkably well-preserved that archaeologists have only begun to discover everything it holds. They are now studying one especially artifact-rich area, known as Regio V, using drones, georadar, lasers, and VR.

SO WHAT: Traditional tools of scientific exploration will be enhanced and augmented by high-tech tools that require high-speed connectivity.



Archaeological Park of Pompeii

DIGITAL TWINS

Advanced simulations connected to the physical world will drive innovation.

Engineers, scientists, and designers have long used digital models in their work, but until recently, these models were isolated from the real world. The next decade will see the proliferation of digital twins, real-time digital models of our homes, cities, factories, and other environs that could enable predictive crystal-ball-like simulations.

“The digital twin is really the digital replica of the operational system,” says Donna Rhodes, a principle research scientist at MIT who runs a research group focused on advancing the design of large-scale, complex, sociotechnical systems.

What makes digital twins so much more useful than isolated models is that they are continuously being refreshed with sensor signals fed to them from the real world. Rhodes offers the example of a wind-turbine farm, which uses GE’s digital-twin technology. Each wind turbine is equipped with sensors, and the data is sent in real time to a computer simulation of the wind farm.

“The model can then be used in decisions,” says Rhodes, “like predicting when a part could be breaking down.”

In some cases, a physical twin must transmit an enormous amount of data to its digital twin. That’s where 5G’s blisteringly fast speed and low latency can make a big difference in

boosting the verisimilitude of digital twins. In the coming years, digital twins will move from engineering labs and factory floors to the world at large. Ubiquitous high-end video cameras that leverage 5G and edge computing for image processing, combined with GPS and other kinds of sensors, will be installed in vehicles (both autonomous and human operated), mobile devices, machinery, and other things, all of which will collect data to create volumetric maps of the world. These photorealistic maps will be the foundation for a wide variety of telepresence, VR, and AR applications.

“As we move forward in the future, we can start to do much more predictive things with digital twins, and have engineering innovations by virtue of the information exchange that goes back and forth between the operational system and the digital-twin model.”

—DONNA RHODES,
PRINCIPAL RESEARCH SCIENTIST AT MIT

Ultrahigh-Resolution 3-D Models

WHAT: Zeiss's photorealistic 3-D scanner, called RealScan, creates extremely detailed digital copies of physical objects that can be viewed in near-microscopic detail.

SO WHAT: The level of detail in gaming, education, telepresence, and virtual reality applications will rival that of the real world and, in some cases, beat it. These kinds of ultrahigh-resolution models will require the speed of 5G networks and the off-device processing capability of edge computing to be truly useful.



Zeiss

3-D Desktop Display

WHAT: The Looking Glass is a non-headgear 3-D display that generates full-color superstereoscopic views of digital models and scenes, and is capable of displaying video at 60 frames per second.

SO WHAT: As more volumetric video is generated and transferred over 5G networks, new methods of display technology will be created to interact with virtual objects and environments.



Digital Twins That Learn

WHAT: SWIM EDX is a software platform that automatically generates digital twins that observe, learn, and adapt to streaming data from complex real-time systems. The company recently used EDX to coordinate the behavior of an autonomous drone swarm.

SO WHAT: SWIM says EDX can “transform operations and deliver powerful insights for a broad set of edge scenarios—including smart cities, industrial automation, utilities and service provider networks, IT, and enterprise infrastructure optimization.”



ANNUAL

Drones online

drone/14922587001 .. SWARM_CONTROL .. 12.193 volts .. 3.98 meters .. 9 mph

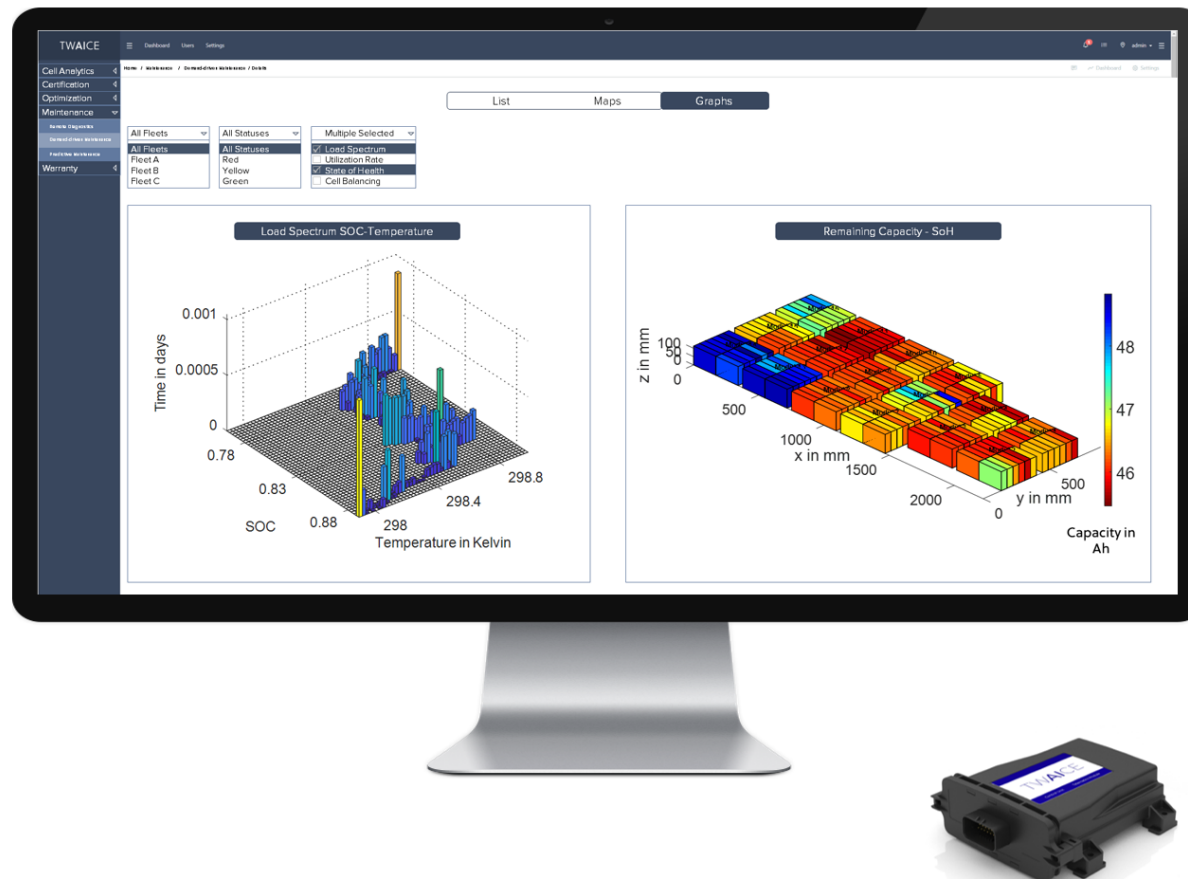
drone/16500116269 .. SWARM_CONTROL .. 12.193 volts .. 3.99 meters .. 8 mph

drone/96516718210 .. SWARM_CONTROL .. 12.193 volts .. 3.99 meters .. 7 mph

Smarter Smart Batteries

WHAT: Twice provides digital-twin solutions to optimize battery design, testing, and tuning for companies with fleets of electric vehicles, as well as for EV automakers. The virtual batteries can help these manufacturers detect problems before they begin to appear in the physical batteries.

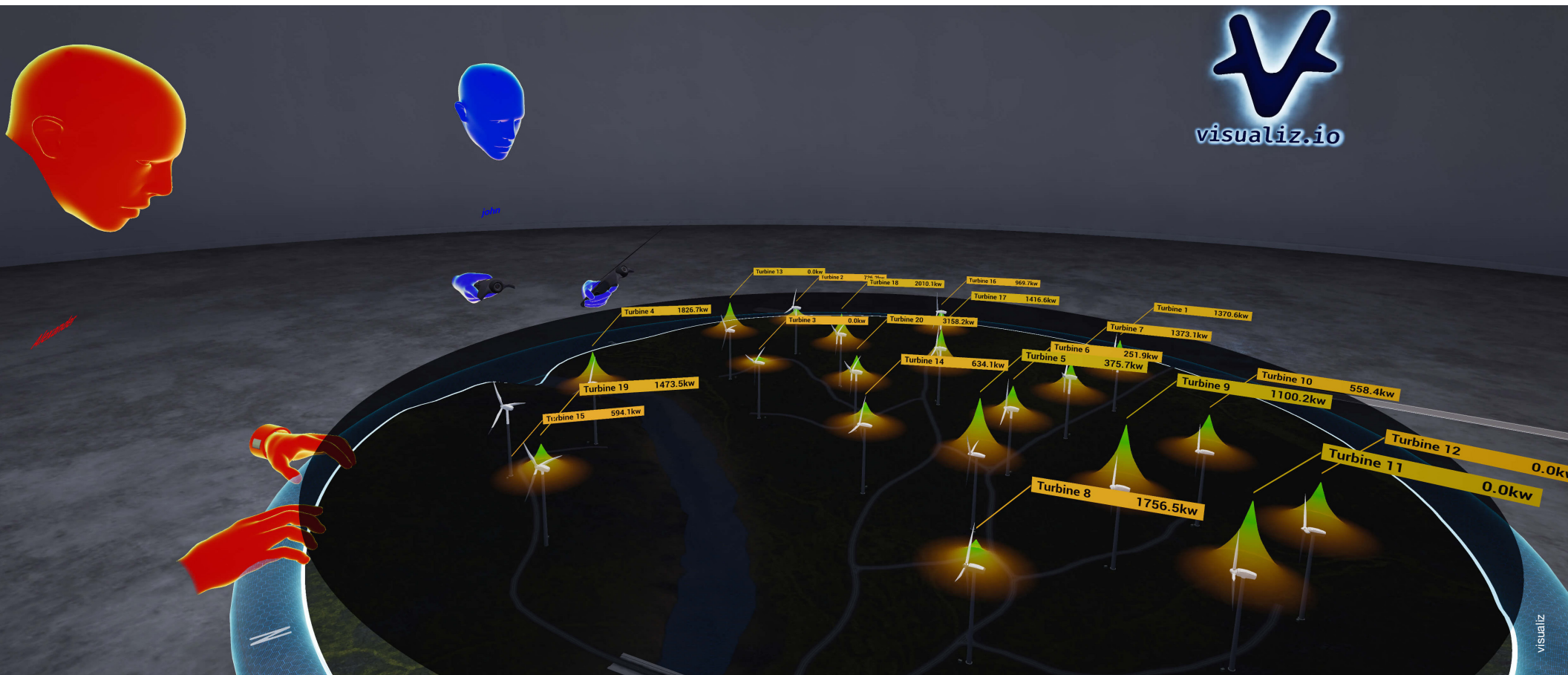
SO WHAT: Digital-twin technology will find its way into every imaginable sector of industry, many of which will be greatly accelerated with 5G network capabilities.



Viewing Factories in VR

WHAT: visualiz makes VR viewable models of entire businesses and factories, which are updated with real-time data from the physical assets and processes in the organization. Multiple remote users can interact with a model at the same time.

SO WHAT: In the future, these kinds of living visual models could replace or augment hard-to-understand reports with much more tangible and interactive representations of reality.



SOCIAL NETWORKS FOR ROBOTS

Tomorrow's robots will teach each other how to navigate our world.

Over the next decade, new species of robots will roll, toddle, and stride into all aspects of our lives, changing the nature of how we work, live, and even interact with one another. edge computing and 5G networks will be the nervous system for robots that are no longer dependent on limited onboard computation or memory. Autonomous vehicles, drone swarms, smart manufacturing systems, and home robots will depend on high-speed, low-latency connections to the network for maps, statistical analysis, and motion planning.

Rather than count on task-specific algorithms, tomorrow's robots will be deep learners, harnessing edge computing to process massive amounts of data in order to get smarter as they go about their business building widgets in highly automated factories, tending fields to optimize crop production, or cleaning our homes safely and efficiently. Most importantly, these robots will participate in social networks of their own to distribute their best practices far and wide.

“Robots will learn from their mistakes and share what they learn collectively so all of the robots improve over time.”

—KEN GOLDBERG, UC BERKELEY PROFESSOR OF ROBOTICS, AUTOMATION, AND NEW MEDIA

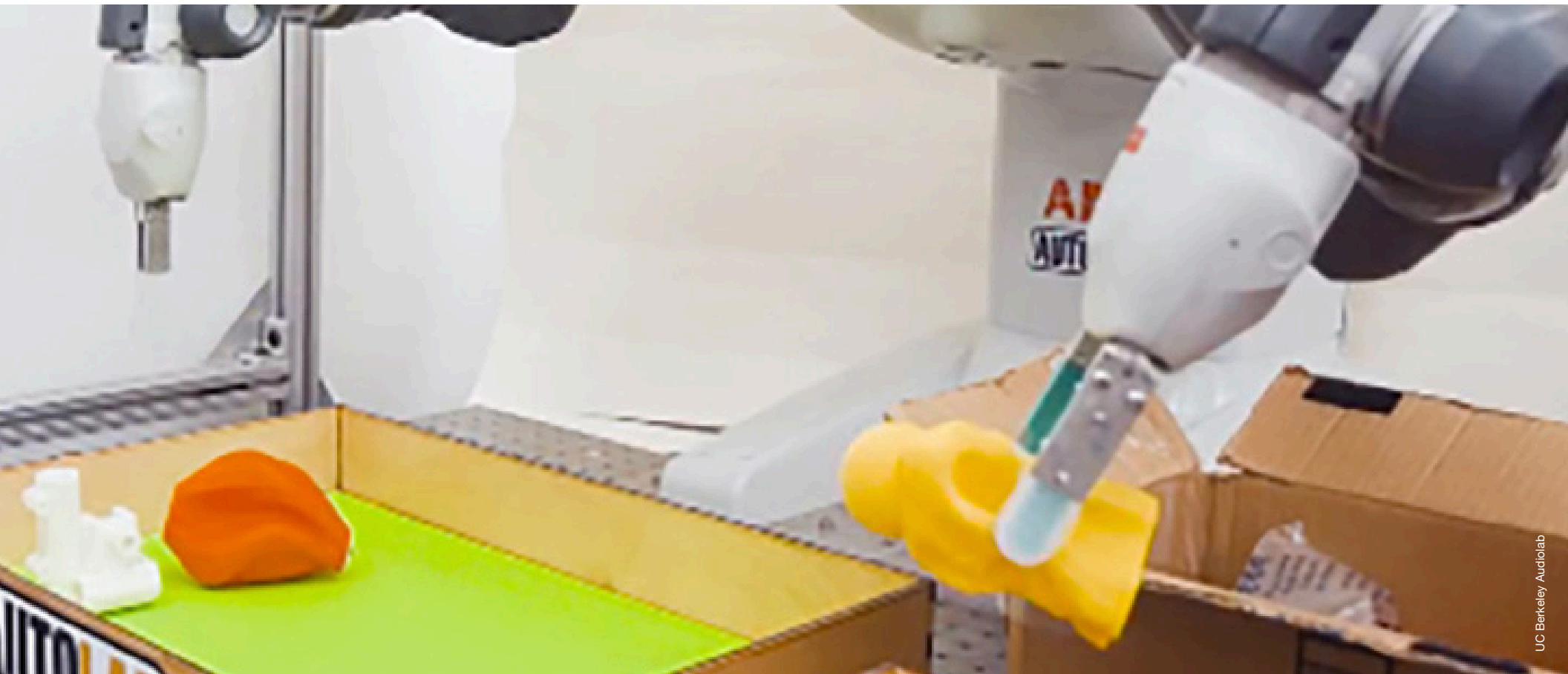
“No matter how much you program a robot, there will always be corner cases, things an autonomous vehicle doesn't recognize, or objects a machine doesn't know how to pick up,” says UC Berkeley professor Ken Goldberg. “If it can't do something, a robot should use a combination of local and cloud processing to analyze the data and figure out what went wrong. Then, once it has learned something, it can update other robots over the network.”

This will be especially important as robots move outside the structured territories of factories, laboratories, and office parks and into the unpredictable environments where most humans live. Of course, the ability of robots to share data about our daily lives—photos or audio recordings, for example—means that extra precautions will need to be taken to ensure privacy and security. After all, just because we invite robots into our homes doesn't mean we want them gossiping about us with their online friends.

Helping Hand for Robot Grippers

WHAT: Developed by UC Berkeley researcher Ken Goldberg and colleagues, Dex-Net as a Service (DNaaS) is a system that uses cloud computing at a central server to calculate robust grasps for object shapes that are uploaded.

SO WHAT: Eventually, such a system could enable a robot in a factory or even your home to ask for help from the network when it encounters an object it doesn't know how to handle.



Robot Delivery

WHAT: Starship Technologies' small robots deliver food and parcels on corporate and academic campuses. Currently, the robots travel autonomously, although a remote operator can intervene as necessary.

SO WHAT: "The introduction of 5G, of course, will be an incredible benefit to our company in terms of maximizing efficiency, increasing speed, and increasing the area in which we can operate," Starship Technologies VP of marketing Henry Harris-Burland told KNect365.



Starship Technologies

A Car's-Eye View

WHAT: The VTT Technical Research Centre of Finland and its partners prototyped the 5G-Safe system for autonomous vehicles to share 3-D views of road conditions and other sensor data between other cars, road operators, and safety services.

SO WHAT: While autonomous vehicles must be able to operate

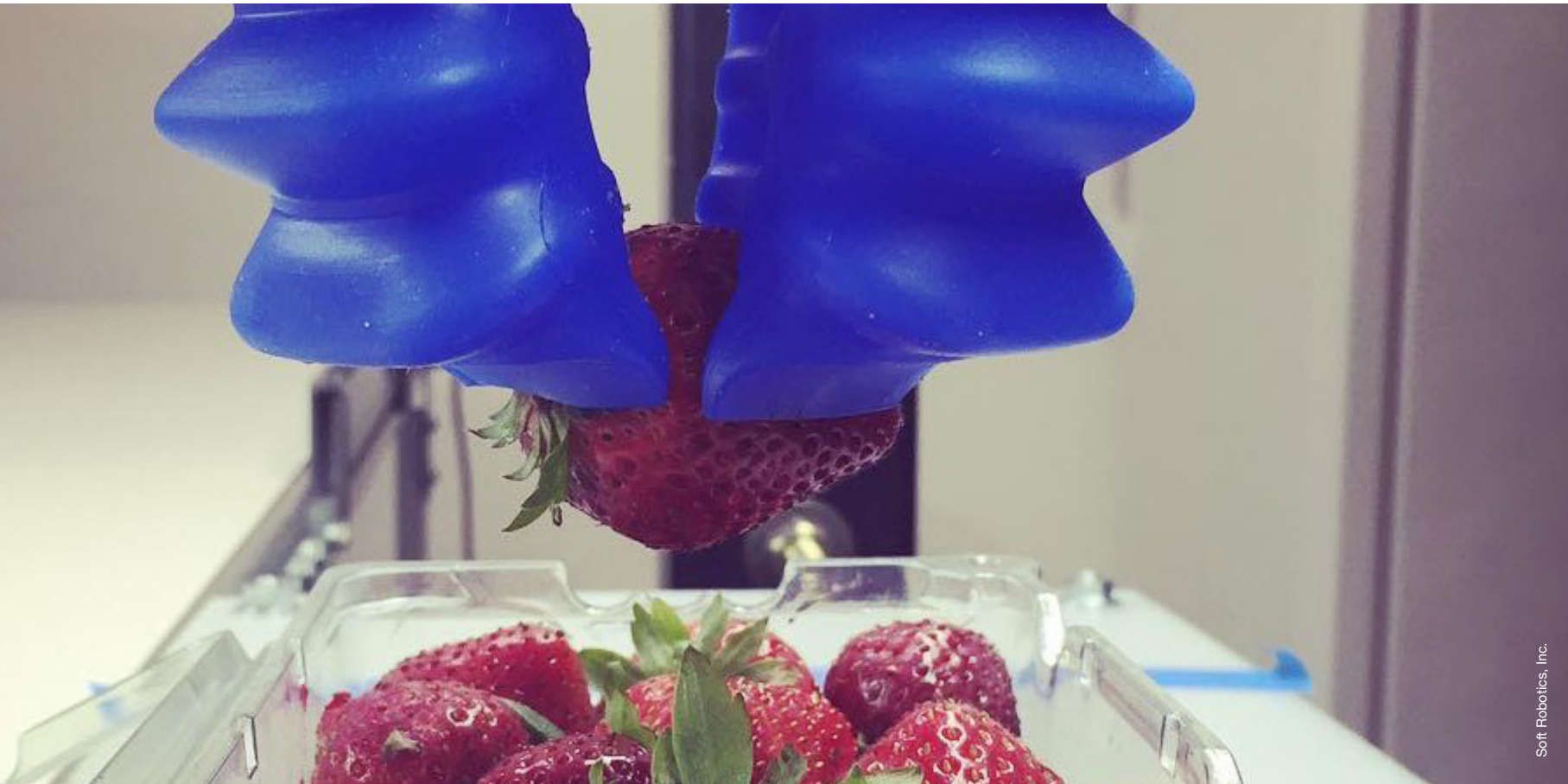
without network connectivity, the 5G-Safe system delivers warnings about what a driver can't see from his or her own vehicle. "Real-time communication and automatic analysis of data allow for faster and more reliable information about the state of the roads," says Oiva Huuskonen of Destia, the Finnish road-construction company collaborating on the project.



Automating Agriculture

WHAT: Soft Robotics, Inc. is developing new applications of its robotic grippers and control systems to automate the harvesting of fruits and vegetables.

SO WHAT: According to CEO Carl Vause, 5G networks could enable networks of robots in unstructured environments like fields to learn “together” about how to better identify and pick ripe produce.



Cloud Robotics in the Sky

WHAT: Rapyuta Robotics' io.drone is an enterprise drone system for applications from security and agriculture to construction and emergency response.

SO WHAT: io.drone integrates with the company's rapyuta.io cloud robotics platform so that additional drones and sensors can easily be added and can share information across the networked infrastructure.



AUGMENTED COGNITION

Tomorrow's experts will be human-computer hybrids.

The best chess player in the world is not a human being. It's not a computer, either. The best chess player in the world is a centaur. This term is used by chess players to describe a human who partners with a computer program to compete in anything-goes freestyle chess tournaments. Centaurs exist outside of chess, too. The best brain-tumor diagnostician is a centaur: a doctor working with an AI software system.

AI-human hybrid intelligence is superior to a lone human or robot because it has an unbeatable combination of a human being's broad knowledge, flexibility, ethical compass, and ancient evolved instincts along with the blindingly fast speed and relentlessness of machine logic. The advent of 5G networks will deepen the human-machine relationship, giving rise to millions of human/AI centaurs who exceed the capabilities of individual human and AI programs —we'll have centaur weather forecasters, centaur soldiers, centaur students, centaur fashion designers, centaur artists, and more. Instead of fearing a robot revolution, we can look forward to working alongside intelligent machines designed to help us successfully achieve our goals.

"In most business situations, our experience has shown that approximately one-third of decisions are optimal, one-third are less than optimal because of limited information, and another third end up being wrong," writes Jesus Mantas, general manager of cognitive-process transformation at IBM Global Business Services. "Cognitive augmentation of processes therefore leads to significant

efficiency because of better decision-making, which typically leads to higher job satisfaction and lower attrition rate in the roles augmented by AI."

In a way, we are already augmented cyborgs—anyone who uses a smartphone to look up information is one. Over the next decade, 5G and edge computing will underpin the formation of new human-machine partnerships that will help us make better decisions, be more creative, learn more efficiently, and achieve goals more quickly.

"Augmenting high cognitive-load tasks with artificial intelligence brings out the best in human operators. From our work at Synapse Technology, we've seen our operator-assist platform significantly increase human job satisfaction, decrease time per task, and increase accuracy rates."

—IAN CINNAMON, COFOUNDER
AND PRESIDENT, SYNAPSE
TECHNOLOGY CORPORATION

Scanning Packages for Threats

WHAT: Every single day, billions of packages and pieces of luggage must be scanned by human screeners for weapons, explosives, and other dangerous materials. Synapse Technology has created an augmented cognition system that uses deep learning and machine vision to analyze the contents

of packages for threats and communicates with human scanners through a friendly user interface.

SO WHAT: AI assistive technology will allow one human to oversee the work of multiple AI assistants.



Virtual Surgery for Real Patients

WHAT: At the Royal London Hospital, physician Shafi Ahmed performed cancer surgery while consulting with two other remote surgeons in augmented reality using Aetho's Thrive telepresence platform.

SO WHAT: Virtual and augmented reality, combined with medical robotics, are poised to transform surgery. Human experts—augmented with real-time patient data and AI at the network's edge—will collaborate in operating theaters from anywhere in the world.



Unmanned Aerial Teams

WHAT: Defense forces have long used unmanned aerial vehicles, but recently the US Army has been deploying teams of manned and unmanned aerial vehicles to increase the likelihood of a successful mission.

SO WHAT: “Unmanned aircraft help to take away the unknown on the battlefield because they can fly out from the Apache and allow the Apache pilot to see over the horizon,” Sean Gilpin, an interoperability lead of the Apache Project Office, told a US Army reporter.



Designs That Evolve

WHAT: Autodesk is incorporating generative design into its CAD products. A human designer specifies constraints for a part (such as weight, size, and strength), and the software mimics the processes of biological evolution to generate designs that meet the specifications.

SO WHAT: Creative people will find new sources of artistic inspiration and guidance from their tirelessly inventive AI partners.



Cyborgs on the Battlefield

WHAT: The US military has entered into “a new era of human-machine collaboration and combat teaming,” said Deputy Secretary of Defense Bob Work in a statement about AI tools that will process large streams of incoming data and suggest courses of action to military personnel.

SO WHAT: AI will manage information overload by analyzing data and helping human partners quickly make informed decisions.



ABOUT IFTF

Institute for the Future (IFTF) is celebrating its 50th anniversary as the world's leading non-profit strategic futures organization. The core of our work is identifying emerging discontinuities that will transform global society and the global marketplace. We provide organizations with insights into business strategy, design process, innovation, and social dilemmas. Our research spans a broad territory of deeply transformative trends, from health and health care to technology, the workplace, and human identity. IFTF is based in Palo Alto, California. For more, visit www.iftf.org.



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