HEALTHCARE: IMPROVING SURGICAL OUTCOMES

AGRICULTURE: A NEW ERA FOR FOOD PRODUCTION

CLIMATE: DRONES CAN HELP TACKLE DEFORESTATION

ROBOTICS

IMPACT 2022

AN FII INSTITUTE PUBLICATION

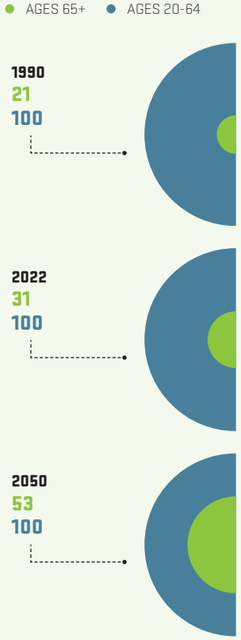
ROBOTICS REVOLUTION
HOW PEOPLE AND PLANET CAN BENEFIT

FII INSTITUTE
Future Investment Initiative Institute
Impact on Humanity

ROBOTICS FACTS

AGING POPULATIONS = FEWER WORKERS

Across OECD countries, the number of people aged 65 and over for every 100 persons of working age (20-64) is rising fast. Robots will become increasingly important for filling this labor gap.

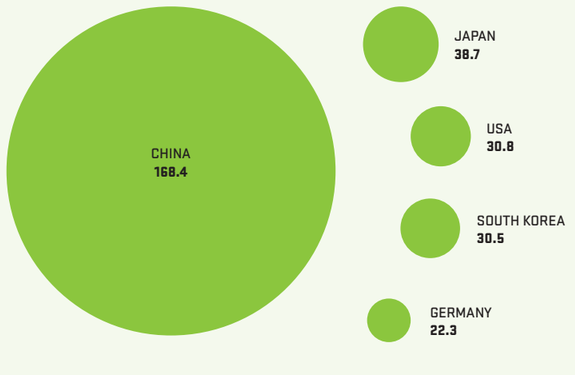


ROBOT-READY AUTOMATION IS GROWING RAPIDLY AROUND THE GLOBE

As technology improves and costs fall, robots are becoming more prevalent, especially in Asia. The sector is set for huge growth, but global attitudes towards automation still vary considerably.

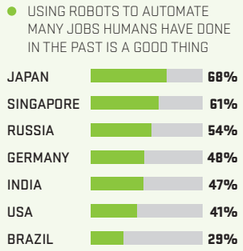
WORLD'S TOP ROBOT USERS

There are now at least 3 million industrial robots operating in factories around the world. Asia, particularly China, is by far the largest market.

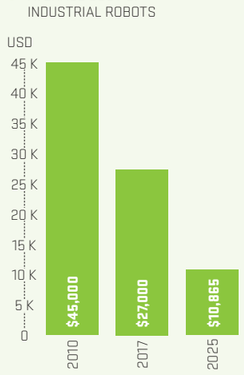


ATTITUDES TOWARDS AUTOMATION

People around the world have varying views on the impact of robotics.

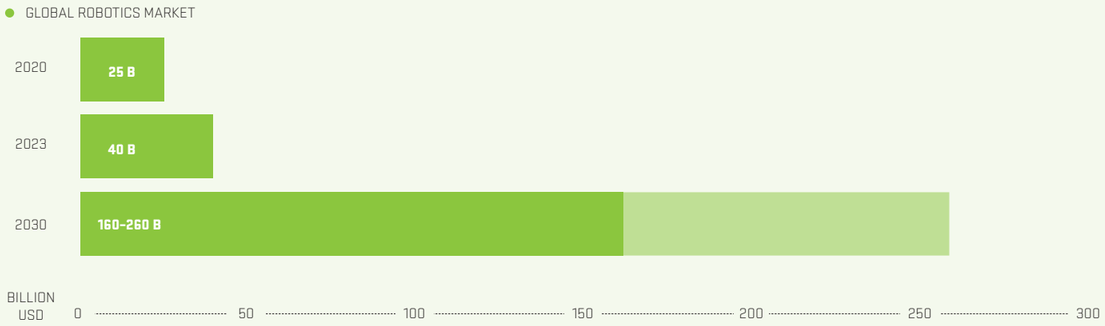


DECLINING COST OF ROBOTS



ROBOTICS POISED FOR HUGE GROWTH

Boston Consulting Group expects the global robotics market to climb from $25 billion in 2020 to between $160 billion (base estimate) and $260 billion (upside) by 2030. Professional services robots will quickly outpace conventional industrial robots and cobots.



SOURCES: HTTPS://WWW.PEWRESEARCH.ORG/FACT-TANK/2020/12/15/PEOPLE-GLOBALLY-OFFER-MIXED-VIEWS-OF-THE-IMPACT-OF-ARTIFICIAL-INTELLIGENCE-JOB-AUTOMATION-ON-SOCIETY/

ILLUSTRATION: ANJE JAGER / SOOTHING SHADE; COVER: SPENCER LOWELL

EDITORIAL

INNOVATION MUST BE ACCESSIBLE TO ALL

FII Institute publishes its fifth impact report as we enter a golden age for innovation in robotics. In the mid-20th century, many scientists and writers envisioned the 2020s as full of highly intelligent robots of all shapes and sizes. While this might not have happened quite as imagined, things are now changing fast.

Technology is rapidly becoming better and more affordable, enabling companies around the world to produce increasingly intelligent and useful machines.

The reality is, we need them. In this report, we highlight how robotics can help us overcome some major global challenges. For example, autonomous farming robots are making agriculture more efficient and sustainable as we rethink food production. Drones can now tackle deforestation and deliver valuable medical supplies to remote areas. And in hospitals, ultra-precise robots are enabling better surgical outcomes.

This report features innovators and researchers worldwide at the heart of this robotics revolution. They share a consensus on three key areas: If we are to truly benefit from these incredible technologies, they must be affordable and accessible to all; robots create more jobs than they replace; and while we cannot overlook the impact of increased automation on workforces, humans and robots can work together to the advantage of both people and planet.

Richard Attias
CEO, FII Institute

CONTACT US:
info@fii-institute.org
@fiiksa FII Institute
Future Investment Initiative

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FII: ROBOTICS IMPACT REPORT 2022

HELPING HANDS

Robots and humans are increasingly able to work side by side. This is a good thing. By collaborating, man and machine can enhance their respective strengths and deliver more effective solutions to serious challenges in areas like food production, healthcare and agriculture.

Fast food

Thanks to its AI-powered system, Foodly can sort food quickly and hygienically. A collaborative robot, it works comfortably alongside people.

FOODLY

RT CORPORATION, JAPAN

PHOTO: SPENCER LOWELL

Delicate touch

Fruit picking is hard work and farm labor increasingly hard to find. Smart, dexterous robots are now able to fill the gap – enabling farmers to focus on other tasks.

BERRY 5.1

HARVEST CROO ROBOTICS, USA

PHOTOS: DINA LITOVSKY / REDUX / LAIF, SPENCER LOWELL

Ultra-precise

Robots can enhance the capabilities of a surgeon's eyes and hands. Tiny instruments offer greater precision, resulting in less invasive surgery.

DA VINCI SURGICAL ROBOT

INTUITIVE, USA

PHOTO: SPENCER LOWELL

Teamwork

The manufacturing sector is one of the biggest adopters of robotics. Around the world, assembly lines like this one are seeing robots evolve from "equipment" to "partners."

NEXTAGE

KAWADA ROBOTICS, JAPAN

PHOTO: SPENCER LOWELL

Moxi, a robotic nurse assistant, helps with non-patient-facing tasks like delivering lab samples and medication. This allows human staff to focus on more important work.

RISE OF THE ROBOTS

HUMANITY IS POISED TO REAP THE REWARDS OF A GOLDEN AGE OF ROBOTICS INNOVATION

Boosting agricultural efficiency: By automating labor-intensive work like planting seeds and bulbs, robots can ensure constant capacity and high plant uniformity.

PHOTOS: SPENCER LOWELL, TOYOTA

THESE ARE GOOD DAYS to be a robot. From warehouses to healthcare and agriculture, the coronavirus has proved to be an effective recruiting tool for robots to come and fill labor shortages.

Amazon's largest warehouse, in Delaware, USA, now has ten robots for every human. Hour after hour in the five-story plant, 10,000 robot vehicles work around the clock in eerie silence to fetch and transport customers' products.

The pandemic brought a boom in online shopping, and Amazon's warehouses couldn't find enough human workers. And not just Amazon. Global investment in automation in warehouses is expected to jump 20% in 2021 to $36 billion.

Meanwhile, back on the farm, half of the 20 biggest vegetable growers in the US now use robot weeders. Like Amazon with its warehouses, farms can't find enough workers. And the global market for agricultural robots is predicted to rise from $5.4 billion in 2020 to more than $20 billion by 2026.

Hospitals, too. In September, the Al Qassimi Women and Children Hospital in the UAE successfully performed 12 robot surgeries in five days. A Scottish family of care homes, Blackwood Homes and Care, is working with the National Robotarium in Edinburgh to introduce telepresence robots that help care for and monitor residents with Alzheimer's. This gives hospital-based carers "the experience of inhabiting a distant robot through which they can remotely guide, assess, and support vulnerable adults," says Dr Mario Parra Rodriguez, a psychology expert at Scotland's University of Strathclyde.

In the early days of lockdown, researchers at Singapore's Nanyang Technological University quickly built a robot to disinfect large surfaces without putting humans at risk. And more than 500 hospitals now use a US-made Xenex robot that can disinfect a patient room in 20 minutes with a pulsed ultraviolet light.

All this was going to happen anyway, but the pandemic means it is happening much faster. Amazon's robot headcount, 350,000 today, is 75% higher than its estimate two years ago. In 2020, the World Economic Forum (WEF) found that 50% of the world's 300 biggest companies are now planning to step up automation in their businesses. By 2025, half of all work tasks will be handled by machines, says the WEF.

We spoke to ten leading global robot experts to help us understand where robots might make the biggest impact and whether we really are in a golden age for robot innovation, as well as for a sneak peek into the robots of the future.

> "We're in the midst of a Cambrian explosion for robotics."

GILL PRATT

Chief scientist,
Toyota Research Institute

NEW CAMBRIAN EXPLOSION

We are in the midst of a "Cambrian explosion for robotics," says Gill Pratt. Now Toyota's chief scientist, Pratt has also served as head of the Robotics Challenge for the US Defense Advanced Research Projects Agency (DARPA).

The original Cambrian explosion took place some 541 million years ago. This is when most of the major animal groups start appearing in the fossil record. "Most scientists believe that the development of vision is what precipitated the sudden evolutionary diaspora," says Andra Keay, managing director of Silicon Valley Robotics, an association that supports innovation and commercialization in robotics.

All life became predators or prey instead of passive energy collectors. It gained a purpose, says Keay, who also researches people and robots at UC Berkeley's Center for Information Technology Research. And as with prehistoric slugs, so with robots. Whether via stereo cameras, lidar, sonar, or something else, robots can now "see" in real time with sufficient accuracy to understand the world around them (see pages 46-47 for more on this topic). And they can now "think" in real time, too – fast enough to take advantage of this vision, thanks to Moore's Law, Keay says.

Add the fact that hardware and sensors are rapidly becoming cheaper due to mass production and you can see why the likes of Switzerland's ANYbotics and US firm Boston Dynamics are selling more and more robots every year. This progress is steadily reducing the price of these machines. Similarly, the development of self-driving cars is lowering the cost of sensors and other crucial hardware. This has been a familiar pattern, from computers to automobiles and aircraft. While the first robot iteration may be extremely expensive, the 10,000th might be pocket change.

MAKING THE BIGGEST IMPACT

"I wasn't sure the world was ready for autonomous cars just yet, so we started with cleaning robots as a first step towards making people's lives easier and better," says Sarthak Yadav, an Indian entrepreneur and chief executive of Aziobot, a robotics start-up based in the Netherlands. In his view, "Robots can make their biggest impact in agriculture and the health and service sectors."

Machine learning is one form of technology driving progress, says Bendik Søvegjarto, head of Oslo aquatech company Bluegrove, which aims to make seafood production more responsible. ↘

By 2025, half of all work tasks will be handled by machines

Drones like the Wingcopter have the potential to make major contributions to numerous sectors, from monitoring farmlands to delivering medical supplies to remote areas.

PHOTOS: WINGCOPTER, VERONICA AHUMADA

Pairing robotics with artificial intelligence enables systems to learn and adapt. In agriculture, this will help the evolution of sustainable methods to grow more food, he says. The result will be the "ecological revolution," helping us produce enough food to sustainably feed a world population set for a 20% surge to 10 billion people by 2050.

Farmers are already adopting robots to milk cows, clean sheds and feed cattle, notes David Leydon, head of food and agribusiness at Ifac, an Irish professional services firm for the farming, food and agribusiness sectors (see pages 22-31 for more on this topic). When feeding a cow, for example, a robot can adapt its feed depending on the cow's life stage and by picking up on sub-clinical diseases a farmer wouldn't be able to identify. Farms will see cobots (collaborative robots) playing a bigger role, Leydon predicts, "as they are smaller, easy to program and can carry out tasks alongside people."

Out in the fields, we are already seeing robots that can zap weeds with precision lasers, eliminating the need for herbicides, says Jeffrey Veltri, head of Prima Energy, a Toronto-based start-up that works on technology to mitigate climate change. And autonomous tree-planting drones are helping to replace some of the natural habitat that humans have removed, he says (see pages 44–45 for more on this topic).

Robots will help scale up agricultural practices that benefit our environment, says Petra Bosilj, a senior lecturer in agri-robotics at the UK's University of Lincoln. "Most farmland grows mono-cultures [a single crop on a large area], maybe with crop rotation. Practices that encourage biodiversity, such as planting different crops together or introducing beneficial insects, rely on manual labor, which limit their efficiency."

Tireless, super-efficient robots can take solutions to a larger scale. Machine vision means robots can treat individual plants differently, so farmers can plant legumes (that fix nitrogen from the air into the soil) next to corn (which likes lots of nitrogen). This can "bring back more complex farming practices that are currently possible through manual tending and which were abandoned in the name of automation," says Bosilj.

In medicine, aging populations and a shortage of hospital workers are pushing healthcare systems to breaking point. One in five UK and US surgeons thinks they'll have to retire early because of the physical demands of their job. But surgical robot helpers could extend surgeons' careers, says Per Vegard Nerseth, chief executive of CMR Surgical, which created a next-generation surgical robot called Versius. The surgical robotics industry "is expected to grow 20% annually," Nerseth says (see pages 54-57 for more on this topic).

The past two years have seen rapid growth in the number of hospitals using robots equipped with manipulators and

> "The past two years have seen rapid growth in the number of hospitals using telerobots."

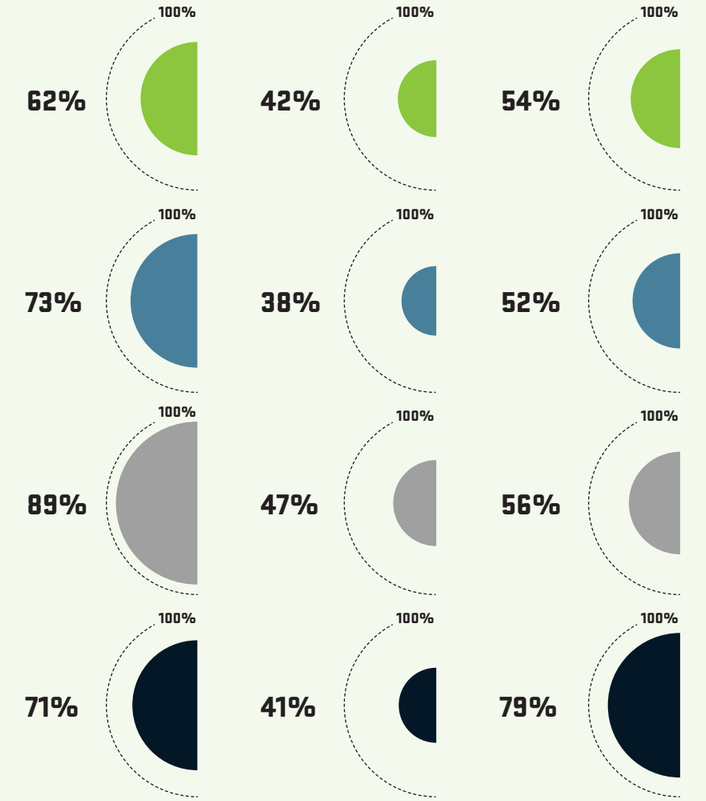
VERONICA AHUMADA

Director of the Technology and Social Connectedness Lab at UC Davis. Also an assistant professor in the UC Davis Department of Pediatrics

TECHNOLOGIES LIKELY TO BE ADOPTED BY 2025

According to the share of companies surveyed worldwide across specific sectors

SOURCE: FUTURE OF JOBS SURVEY 2020, WORLD ECONOMIC FORUM



grippers, reducing the number of times clinical staff need to enter a room with a Covid patient, says Veronica Ahumada, an assistant pediatrics professor at the University of California, Davis.

Some grippers look like hands, others come with suction cups. Robot hands have the advantage of not getting tired. A Japanese robot by the name of Robear helps patients to get in and out of bed and wheelchairs. Robots can also deliver personalized, timed reminders to attend check-ups or take medicine.

Ahumada and her colleagues recently received a $1.2 million grant to research how healthcare workers can use robots to treat patients with Covid-19 and other infectious diseases. With some 6 million people medically homebound in the United States alone, the potential market for assistive robots is huge.

ROBOTS FOR ALL

In some countries, technologies such as smartphones have helped rapidly open up access to areas like financial services and education. "In the same way, robotics might enable these countries to speed up development in healthcare or agriculture," says Marko Bjelonic, a roboticist at Swiss research institute ETH Zurich.

On the other hand, robot features that work in the US "may not translate effectively to communities in Mexico, Denmark or Germany," says Veronica Ahumada, who also directs the UC Davis Technology and Social Connectedness Lab. So teams in each of those countries are working on developing "culturally appropriate robots," she says.

In India, there is a growing number of robotics start-ups – like logistics firm GreyOrange, which has raised $140 million – that are first commercializing solutions for India, and then going global. GreyOrange has an international hub in Singapore and is turning its Atlanta outpost into a new global headquarters, with a possible listing in New York to follow.

HUMAN VERSUS ROBOT

A robot revolution will create about 97 million jobs worldwide – and remove an equal amount, predicts the World Economic Forum. So part of preparing for the rise of robots is investing adequately in retraining for people whose jobs might be taken by a robot, especially those in routine, manual work.

Collaborative robots could increase workers' productivity. This is the "reinstatement effect"

In the long term, collaborative robots could actually increase many workers' productivity, leading to higher wages and the creation of new tasks and jobs. "This is known as the reinstatement effect," says Adriana Rodriguez Rivera, a researcher in climate change policy based in Madrid. "However, the path to this equilibrium in the labor market will not be easy."

Andra Keay turns the question of whether workers should fear robot labor on its head. It's the companies that don't invest in robotics at this pivotal time that "will almost certainly be in financial difficulty in the future. That's when workers should be afraid," she says.

ROBOTS OF 2031

So will we have a long wait to see the robots of a decade from now? Or can the world's most brilliant roboticists provide us with a sneak peek?

Multi-robot systems, or "marsupial robots," as featured recently in the DARPA Subterranean Challenge, are something we'll be seeing a lot more of, predicts Keay. The name is apt. One larger robot carries several smaller robots for deployment, and each system has complementary capabilities. Ultimately, "this is how we will explore other worlds in space, and difficult or dangerous terrains on Earth," she says.

In healthcare, for the first time "we have a real-time digital interface between the surgeon and patient that will produce all sorts of data from a procedure that would otherwise be lost," says Per Vegard Nerseth. Once you couple this data with clinical outcomes, that result is going to be a "much better understanding of which techniques equate to better outcomes," he says. Better surgery, by getting patients home faster, also frees up hospital beds.

From climate change and farming to hospitals and caring for the aged, robots are set to help address many of our most dispiriting problems as a species.

And so, fueled by AI and the Cambrian explosion in vision, the robot will see you now. ■

Smart indoor farms can monitor and control conditions. This helps grow more food from fewer resources, improving efficiency and sustainability.

PHOTO: SPENCER LOWELL

CALL TO IMPACT

1 Hardware and sensors are becoming both cheaper and increasingly powerful, ushering in a new golden era of robotic innovation.

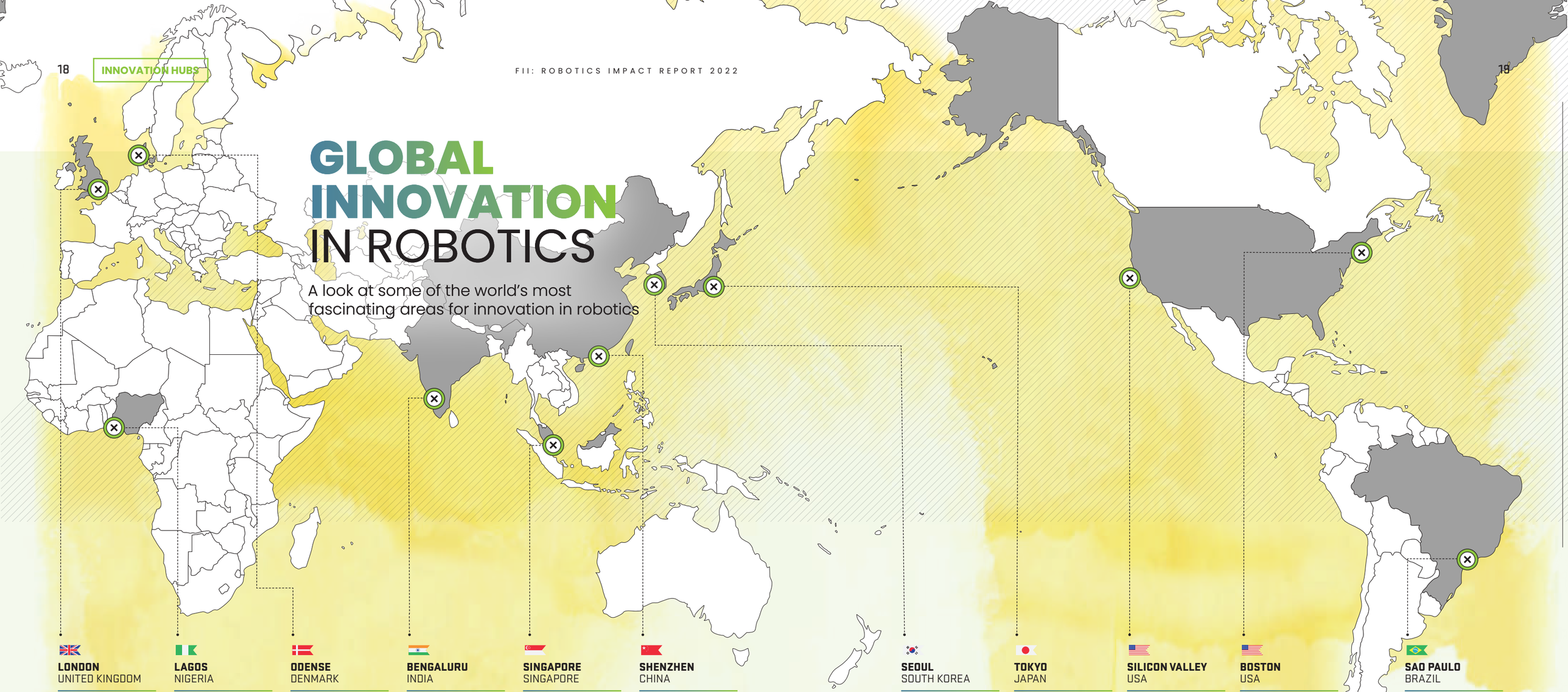
2 This will enable robots to help overcome several major global challenges. They can drive efficiency to boost sustainable production across multiple sectors, as well as help solve serious worker shortages. By 2025, half of all work tasks will be handled by machines, says the World Economic Forum.

3 A robot revolution will create about 97 million jobs worldwide – and remove an equal amount. It is vital to invest adequately in retraining for people whose jobs might be taken by a robot, especially those in routine, manual work.

4 In the long term, advanced robotics could actually increase workers' productivity, leading to higher wages and the creation of new tasks and jobs. However, this path will not always be an easy one.

GLOBAL INNOVATION IN ROBOTICS

A look at some of the world's most fascinating areas for innovation in robotics



LONDON
UNITED KINGDOM

Europe's tech capital is welcoming record amounts of investment into a range of robotics and AI companies. They cover everything from Deep Mind's incredible AI research lab to online supermarket giant Ocado's robot-powered warehouse.

LAGOS
NIGERIA

Nigeria has the most innovation hubs in Africa, with many located in the Yaba district of its capital city. Fintech may still dominate the tech scene, but AI and robotics are attracting increasing attention and the likes of Facebook and Google are opening up offices to tap into the huge pool of local tech talent.

ODENSE
DENMARK

Denmark's "robot island" has 150 robotics companies in a community of just 500,000 people. They cover everything from hospital decontamination to cobots aimed at smaller businesses and human-robot collaboration. It's also home to Denmark's national robotics cluster, which unites the country's robot ecosystem.

BENGALURU
INDIA

India's innovation capital was named the world's fastest-growing tech hub in 2021, according to the growth in investment. It is also now home to a new AI and robotics technology park, which aims to foster technology that maximizes societal and environmental impact.

SINGAPORE
SINGAPORE

Established in 2016, Singapore's National Robotics Programme has made the city state a world leader in robotics. It now has the highest adoption rate of industrial robots in the world, with 9 per 100 workers.

SHENZHEN
CHINA

China buys and builds more industrial robots than any other country and has set ambitious "Made in China 2025" goals to make more of its robots at home (currently 39%). Shenzhen has long been dubbed "China's Silicon Valley" and is home to more than 6,500 companies related to robotics.

SEOUL
SOUTH KOREA

One of the world's most tech-savvy countries, South Korea trails only Singapore in its adoption of industrial robots. In an economy that is heavy on electronics manufacturing, robots have made great gains by taking on simple, repetitive tasks.

TOKYO
JAPAN

Japan is the world's largest robot exporter, accounting for one-third of all exported industrial robots. They have an increasingly important role within the country, too. A rapidly aging population means Japan's workforce will be 20% smaller in 2040 than it was in 2017. The capital city is a hotbed of research and investment in companies large and small.

SILICON VALLEY
USA

As you'd expect, the world's foremost tech center is vital for robotics. One current trend: rent-a-robot start-ups are flourishing, catering to manufacturers who are struggling to source workers but don't necessarily have the cash or desire to buy robots straight out.

BOSTON
USA

Founded in 1992 as an MIT spin-off, Boston Dynamics has long captured attention with its viral robot videos that showcase their creations' incredible agility and control. It's far from the city's only attraction: an abundance of world-class research and educational facilities make the area an important hub for robotics across a variety of industries.

SAO PAULO
BRAZIL

The Brazilian city is emerging as a world-class AI innovation hub and a growing center for robotics, particularly in agriculture. It is also home to a major new AI research center, a partnership between the government and IBM, which is tackling challenges in health, food production and the environment.

ILLUSTRATION: LAURA RISSE MAP SOURCE: FAO

RETHINKING FOOD PRODUCTION

ROBOTICS CAN MAKE AGRICULTURE MORE EFFICIENT AND SUSTAINABLE. BUT TECHNOLOGY MUST BE ACCESSIBLE TO ALL

Thorvald, from Norway's Saga Robotics, can perform a variety of tasks, from picking to data collection to UVC light treatment.

PHOTO: SAGA ROBOTICS AS

Agricultural drones can make crop management safer and more efficient.

PAUL VOUTIER has spent the last decade looking at challenges facing small farms in Asia. There are some 73 million smallholdings - farms that generate both food and income for a single family - in Southeast Asia alone. "I've always been fascinated by how we can improve their productivity and profitability," says Voutier, senior advisor to World Economic Forum initiative Grow Asia and founder of Ambit Robotics. "What sort of technologies are emerging and how are smallholders using them? What business models will engage these farmers in a commercially viable way?"

Robotics, he believes, could be part of the solution. And he isn't the only one.

From a robot that can pluck fresh strawberries in California to drones that can map vast swathes of farmland in South America and AI-powered weeding bots in Kenya, there are now hundreds of thousands of robots deployed across the global food supply chain. According to predictions from Bis Research, the value of the global agriculture robots market will rise from $1.9 billion in 2019 to $7.7 billion in 2025, a growth of more than 300% in six years.

IMPROVING PRODUCTIVITY

Robots can help farmers deal with the perfect storm of pressures they currently face. "Climate change, food shortage, an aging society and population growth, to name just a few," says Fumiya Iida, a reader on robotics at the University of Cambridge. "It is estimated that food production has to rise 50% on average in the next decade or two, while [at the same time the] working population decreases and wages increase." All of which means, he adds, "technological advancement must be in place to achieve this target."

But how exactly is robotics the answer to agriculture's biggest woes?

Within 30 years, the world will have two billion additional mouths to feed, according to the United Nations. At the same time, the supply of viable arable land is dwindling, with an estimated 25% of supply already rendered unusable due to rising temperatures and increased drought, according to a report by the United Nations' Intergovernmental Panel on Climate Change (IPCC). Robots, which can now operate more precisely and efficiently than humans in many tasks, can help improve the productivity of the remaining land.

> "What are the business models that will engage farmers?"

PAUL VOUTIER

Founder, Ambit Robotics, and senior advisor to Grow Asia

Take the Chinese XAG Agricultural drones currently zooming around the Andes mountains in Ecuador. With more than half of this South American country at an altitude of 3,000 meters or higher, vast swathes of farmland have been left unused, too challenging to farm efficiently. But trials are now underway in which the high-powered drones take on the job of spraying these high-altitude crops, reducing both the labor involved and exposure to pesticides. Local youths in the area are even being trained to pilot the XAG drones themselves.

PHOTOS: COSTFOTO / BARCROFT MEDIA / GETTY IMAGES; TATYANA KILDISHEVA

Elsewhere, robotics is helping to tackle a dwindling supply of labor. In the UK, Brexit has left British farmers facing a severe deficit of seasonal workers, 99% of whom previously came from the EU. It's against that backdrop that robots created by the likes of Xihelm, a British start-up run by former Google staffer James Kent, are gaining traction. Its robotic glasshouse harvester Eagle, with an AI-powered arm that detects and plucks the ripest fruits, may eventually be able to reduce the numbers of workers needed during peak harvest periods by as much as 70%, according to Kent.

Then there is climate change. Or more specifically, the exposure of crops to increasingly extreme weather events. Even in largely temperate Europe, the severity of the impact of heatwaves and drought on crop production has roughly tripled over the last 50 years, escalating losses from just 2.2% in 1964 to 7.3% in 2015. In developing countries, the impact is much worse. The IPCC has estimated a 50% drop in yield from African farmland, and a staggering decline of up to 90% by 2100.

> The IPCC has estimated a 50% drop in yield from African farmland and a staggering decline of up to 90% by 2100

COLLABORATIVE DEVELOPMENT

In this area, too, robotics could provide solutions. In Japan, for example, huge indoor farms are now being tended by state-of-the-art robotic arms [see pages 32-35 for more on this topic]. At the Keihanna plant, a few kilometers north of the city of Nara, these robotic arms can transplant delicate lettuce seedlings into giant racks to be warmed under LED lights. Around 30,000 lettuces can be produced every day this way, with zero risk of exposure to extreme weather.

But in Japan, average income sits at around $46,000. In Kenya, it's $7,000. This is a crude example of the challenges faced in creating truly scalable robotic solutions that are as advantageous to smallholders near Nairobi as they are to affluent vertical farmers in Tokyo.

A key element is greater collaboration between engineers and agribusinesses. Demand is there from farmers, says Niall Mottram, head of industrial and energy at global product development and technology consultancy firm Cambridge Consultants. "There is a growing frustration from the farming community. People are saying, 'Look, I've heard about these robots for a few years now, but where are they?'" But the best solutions need to be collaboratively developed.

In 2015, the Western Growers Center for Innovation & Technology opened

its doors with just this in mind. Based in the small Californian city of Salinas, the center was created to help growers cooperate directly with those behind the technologies; a way to provide feedback on costs, priorities, and more. It gives the start-ups an opportunity to have a more informed conversation with a wider cross-section of potential customers," says Mottram. "And at the same time the growers get to steer the development of robotics."

AFFORDABILITY IS CRUCIAL

In so doing it may also help address the second big challenge: funding. On the one hand, collaborative ventures between tech companies and agribusinesses, like John Deere's 2017 acquisition of Blue River Technology for $305 million, breed interest from private investors. On the other hand, it helps ensure the robot is sufficiently cost-effective.

> "A robot needs to do a lot of things so it starts to have the value proposition of a human."

NIALL MOTTRAM

Head of industrial energy, Cambridge Consultants

It's now widely accepted, for instance, that to be affordable to farmers, a robot can't simply replace the single function of a worker. Instead, it needs to be a multitasker. "It's no longer about just picking a strawberry," says Mottram. "A robot needs to do lots of other things so it starts to have the value proposition of a human. When you get that modularity, the economics begin to stack up. Otherwise, it's a tough sell."

At Norwegian manufacturer Saga Robotics, this way of thinking inspired the design of their robot, Thorvald. Both modular and multifunctional, Thorvald is capable of maneuvering through polytunnels (a polythene-covered hoop greenhouse) or adjusting its height to work in vineyards. It can also function as a sensor platform to monitor crops and soils, as well as picking fruits, cutting grass, and spraying.

PHOTOS: MATT MUNRO, XIHELM LTD, CAMBRIDGE CONSULTANTS

> These technologies must be just as viable in developing countries as in existing robotics powerhouses

What cost-effective means exactly will vary wildly depending on geography. Ultimately, these technologies must be just as viable in developing countries as in existing robotic powerhouses like the US, Singapore and Europe.

This is why, when Voutier set up Ambit Robotics in 2019, he set his team a budget of just $1,000 per robot and focused on a particularly onerous and inefficient task: crop spraying. Many smallholders still use a knapsack loaded with pesticide and carry out the job by hand. It's slow, hot and dangerous - regular exposure to pesticide can cause serious health damage. But, at a width of just 30cm, the Ambit Robot is agile enough to take their place, moving between the narrow lanes that separate rows of crops. The robot responds to an Android app that marks out the spraying area and, capable of covering a hectare per hour, it can cut the length of the job by 80%. Weighing only 5 kg, it is also light enough to be shared between farms. That's critical, says Voutier. "Otherwise, the economics just kill you." The technology is now being trialed across India, Indonesia, and Thailand

With 80% of the world's food supplied through smallholder farms, each with limited budgets and physical idiosyncrasies, it's a targeted approach that many others in robotics will need to replicate. Yes, robotics could help address the challenges facing global food production. But in order to do so, its creators will need to address affordability, accessibility and scalability. ■

Thorvald, from Saga Robotics (far left) is equally at home in polytunnels and open fields. Xihelm founder James Kent (left) and the Eagle harvester.

CALL TO IMPACT

1 Farmers around the world are facing a variety of challenges, including climate change, food shortage, an aging society and population growth. Food production must rise 50% on average in the next decade or two, while the working population decreases and wages rise.

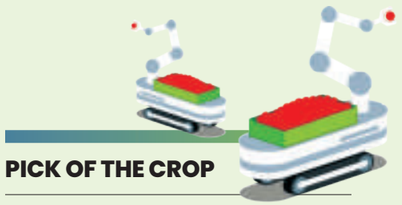
2 Arable land is shrinking, but robots can help with precision agriculture to improve productivity. They can also take on exhausting manual labor and reduce exposure to dangerous pesticides.

3 Solutions must be scalable, accessible and affordable to farmers around the world. This requires greater collaboration among engineers, agribusinesses and investors.

THE ROBOT-ASSISTED FARM

From crop-spraying drones to automated weed killers and milking machines, robots are helping transform many labor-intensive areas of farming. This can increase efficiency, minimize environmental impact and enable farmers to focus on more creative tasks.

ILLUSTRATION: JÖRG BLOCK



PICK OF THE CROP

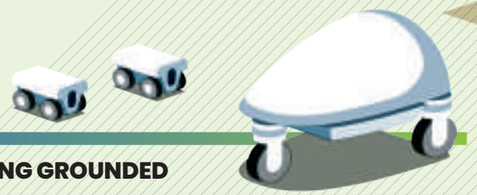
→ Picking fruit requires a light touch and fine judgment of ripeness. Robots are proving an increasingly capable ally. Human fruit pickers can call robots to collect filled containers, increasing productivity. And while robot pickers can't quite match people in terms of speed, technology is rapidly improving. In the background, forecasting algorithms predict yields, plan labor and match supply and demand when it comes to harvest season, helping farms to reduce waste.

AIMING HIGH

→Autonomous drones are an increasingly valuable eye in the sky for farmers. Using multispectral sensors, they can capture detailed data on crop size and health or precisely map large areas to plan irrigation and treatment, reducing land damage from over-farming. Drones can also treat crops and sow seeds themselves. This is especially useful for reducing labor in hard-to-reach farming areas and can lower human exposure to pesticides potentially harmful in large amounts.

LOOKING AFTER ANIMALS

→ It isn't just crops. Robots can also help manage livestock. Laser-guided robotic milking machines enable cows to be milked when they want – meaning happier cattle and better milk. Feeding robots move up and down barns administering food and water at set intervals, allowing farmers to focus on other tasks.



STAYING GROUNDED

→ From 30-cm crop sprayers to mighty machines standing several meters high, robots can handle a growing number of tasks in the field. Autonomous weeding bots identify and remove individual weeds without harming crops. By shining intense bursts of UV light on crops at night, robots can also help reduce diseases that harm plants. On a bigger scale, autonomy is now being added to large tractors, so they can plough fields without human help. At the heart of this is a central fleet control system to manage traffic and alert farmers when robots require charging or maintenance.

PACKED AND READY

→ A significant portion of farm labor isn't out in the fields but in fruit and veg packing centers. Robots are being adapted from production line technology to improve speed and efficiency.

FII: ROBOTICS IMPACT REPORT 2022

ROBOT FARMERS

At Clock House Farm in southern England, where around 900 workers typically pick, sort and pack fruits by hand, a team of farmers, scientists and engineers aims to showcase how robotics can lend a hand.

IN 2020, Robot Highways, backed by a consortium that includes the University of Lincoln, Saga Robotics, the University of Reading, telecoms giant BT, and Berry Gardens Growers, was boosted by a £2.5 million ($5 million) investment from the UK government. With a planned delivery date of 2025, the project will combine a variety of autonomous innovations to create the world's first robotic farm.

In this interview, Simon Pearson, a professor of agri-food technology at the University of Lincoln and director of the Lincoln Institute of Agri-Food Technology (LIAT), explains what that could look like, what challenges the team faces, and why such a project is necessary.

Simon, can you tell us more about the concept of Robot Highways and how you came to be involved?

Simon Pearson: I call myself an agricultural technologist. I'm from an agricultural and engineering background. My head works as an engineer, and my heart works as a farmer. Our activities at LIAT are interdisciplinary. We work with engineers, computer scientists, geographers, social scientists and businesspeople. We're an access point to the agri-food domain, which is a great place to be as it has real challenges. There's a massive shortage of workers, high use of water and pesticides, and a lot of food waste, as well as a need to create high-skilled jobs on farms. So, agriculture is a great place to deploy our interdisciplinary skills and create solutions.

Robot Highways is the culmination of four years' work and multiple projects around robotics and data science. This is the first time we've joined it all up away from a laboratory – or our research farm at Lincoln – and brought it to a real farm.

It's the next obvious step for what we want to do. We don't want to just do research; we want to get these robots out into the real world. Robot Highways aims to demonstrate seven technologies on one farm.

Can you talk us through these seven technologies?

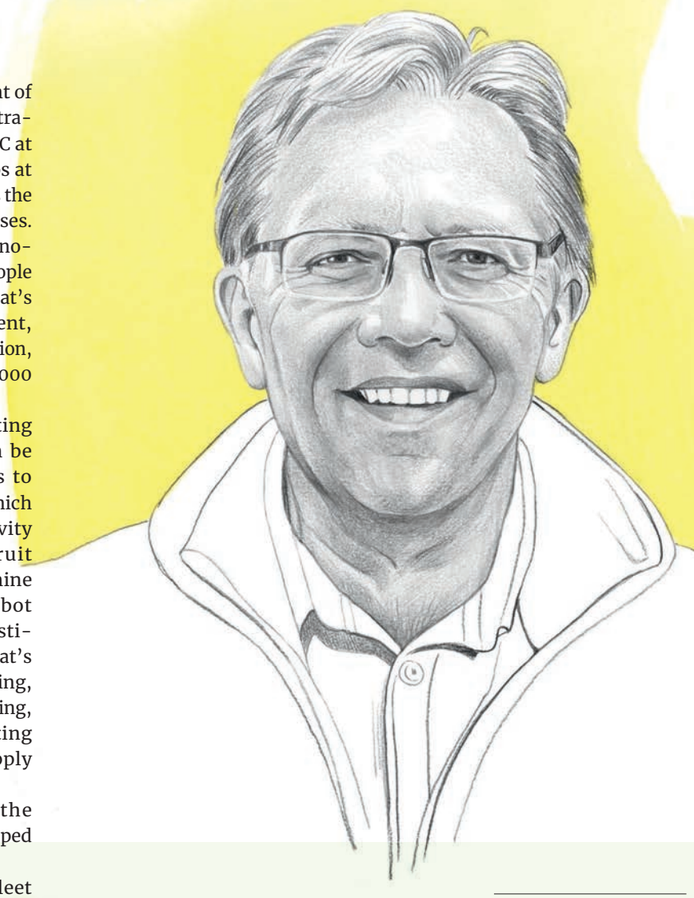
The first is autonomy; the ability for a robot to navigate from A to B on its own. That is really challenging and the foundation of all the other robotics technologies we've got.

Once you've got a robot that can move around, you can do lots of other things on it. So we're using a new treatment of plants with UVC, a type of ultraviolet light. If you shine UVC at night onto strawberry crops at fairly high intensity, it stops the growth of many plant diseases. To do that you need an autonomous robot for safety, so people aren't exposed to the UV. That's been very successful. In Kent, we've got 12 robots in operation, which have already done 5,000 miles of treatment.

The next layer is assisting fruit pickers. Robots can be called by manual pickers to collect filled containers, which drives up picker productivity by about 20%. Then fruit forecasting: using a machine learning algorithm, a robot can count, measure and estimate the weight of fruit. That's fantastic for yield forecasting, operational and labor planning, reducing food waste, setting prices, and matching supply and demand.

The fourth layer is the robotic crop sprayer developed by [Norwegian firm] Saga.

And then you need a fleet control system to manage the traffic, the maintenance of the fleet, the battery charging for the fleet and the route planning around the farm, which is an unstructured environment.



PHOTOS: KRISTOFFER SKARSGAARD; ILLUSTRATION: ULI KNORZER

Saga Robotics' Thorvald platform is being used as an autonomous crop sprayer.

Next is fruit picking by robots themselves. We're not at anything like a human picker's pace, but have demonstrated we can pick fruit. The final part is what to do with the fruit in the pack house. About a third of workers are in the pack house not the farm, so we're trying to automate some of the work flows there to drive productivity. It's quite an integrated project with lots going on.

Why is it significant to show all these technologies integrating on a single site?

What tends to happen with robotics start-ups is they get so far and then they collapse as they can't have a scalable business model. What we've tried to do here is to go big and really try to get a scalable business model, both for the robot company and for the farm. So the farm only has one independent platform, and the business case for the robot company is also viable as they have seven revenue streams in the software stack from one farm. That's really important to make it economically sustainable.

Have you come across any unexpected challenges so far?

Using a lot of different technologies at the same time provides a massive data problem. There's huge amounts of data swarming around these dozens of robots on one farm. So we've got BT working on upgrading our onsite connectivity, which is likely to be 5G. It's only by demonstrations like this that you face that sort of real-world problem. Of course, then we have got to solve those issues, because if we don't, we aren't going to make any progress. And those farms, given the state of the labor market at the moment, are going to be in trouble.

What else do we need to bear in mind when it comes to scaling up robotics on farms?

You've got the headache of the skills challenge on farms. I used to run one and I think we had 900 pickers, too. What happens on a farm like that is your middle management are trained as labor managers, who do a fantastic job. But what you've got to do is take that middle management and, rather than have them managing people, you've got to help them manage robots. That's a completely different skills challenge that you need to work on. You can't leave anyone behind.

The project aims to be finalized by 2025. How hopeful are you of hitting that target?

We're on track. The big question we've not worked out yet is the viability of the business model, as it has to work for everybody. It's got to work for the farmer and for the robot company, and it's only by looking at the full stack of opportunities from these robots that we'll know if it's really viable from a business perspective.

We might also hit some regulatory barriers, or health and safety barriers, we haven't yet anticipated. But, as I say, it's only by demonstrating at scale that you get to those real-world challenges. You can think of them in a laboratory, but you'll never see them until you get on a real-life farm. ■

> "We don't want to just do research; we want to get these robots out into the real world."

SIMON PEARSON

Professor of agri-food technology at the University of Lincoln and director of the Lincoln Institute of Agri-Food Technology (LIAT)

INSIDE TRACK

INDOOR FARMING CAN HELP FEED GROWING URBAN POPULATIONS WITH FRESH, SUSTAINABLE PRODUCE

PORT SHUTDOWNS, shipping route disruptions, a chronic shortage of delivery drivers and, of course, the global pandemic have recently highlighted the weaknesses in our global food supply chain. At the same time, our changing way of life means delivering food is becoming harder than ever – by 2100, according to the United Nations, 9 billion of us will be living in cities worldwide, compared to less than 1 billion in 1950.

One solution is to move food production closer to the people. But traditionally, farming has been highly land- and resource-intensive. Some 10% of the world's cropland is vulnerable to a likely reduction in water availability, while the human sprawl is encroaching on land once devoted to producing food.

A raft of new tech-enabled start-ups, however, thinks there's a way forward. The idea is simple: large farms traditionally rely on nature and its whims to work. But now it's possible to make your own nature, indoors. Smart systems can precisely monitor and control everything from soil acidity to light and water levels, enabling optimal growing patterns. When they're ready to be harvested, the plants are picked – often by robotic machines that whirr and whizz around the facility. The aim? Maximum efficiency.

"It's now possible to create a predictable growing environment for every harvest that you can do almost year-round," says Jeffrey Landau, director of business development and partnerships at Agritecture, a leading advisory firm on urban and controlled environment agriculture. Worries that have blighted farmers' lives for centuries – droughts, floods, rainstorms and snap sunny spells – could be a thing of the past.

"Interest in the industry has come a long way," says Landau. "We've seen a lot of high-profile failures, a lot of new technologies, and a lot of changes in the perception of how food is grown and where it should be grown, particularly since the pandemic."

AGRICULTURAL REVOLUTION

That's what drives those running vertical and robotic farming start-ups to pursue their new businesses. "To feed everyone a healthy diet, we need to grow three times more food with less land and water," says Nate Storey, co-founder and chief science officer at San Francisco start-up Plenty. "That will require an agricultural revolution, and indoor vertical farming is a vital part of the solution. Vertical farming allows fruit and vegetable production to grow at exponential rates without wiping out forests for agriculture."

Storey claims Plenty can produce more crop cycles in a year than an outdoor farm can in an entire lifetime – meaning ↘

> **"We've seen a lot of changes in the perception of how food is grown."**

JEFFREY LANDAU

Director of business development and partnerships, Agritecture

US start-up Plenty says it can produce more crop cycles in a year than an outdoor farm can in an entire lifetime.

PHOTOS: SPENCER LOWELL / PLENTY; JEFFREY LANDAU

Indoor farms combine man and machine to closely monitor and control growing conditions, from light to water levels. This can reduce land and water use by well over 50%.

CALL TO IMPACT

1 By 2100, 9 billion of us will live in cities worldwide, according to the United Nations, compared to less than 1 billion in 1950. This will create added pressure on the global food supply chain.

2 Farming is traditionally land- and resource-intensive, as well as highly reliant on nature. But indoor farming can drastically reduce land use and significantly increase efficiency and productivity.

3 Smart systems can create optimal growing conditions all year round, wherever the farm. Food supply chains could become much shorter, improving sustainability.

4 However, challenges remain: technology costs are high and crop diversity is limited.

5 Ultimately, indoor farming will be just one (albeit important) solution in a larger toolbox to create stronger agricultural food systems.

↘ more food using fewer resources. It does this by cutting down on the natural waste inherent in traditional farming processes.

The pandemic is providing a growth opportunity for major players in the field. German vertical farming company Infarm started out with a small number of sites that has now ballooned to more than 500 locations across Europe, North America and Asia.

GROWING MORE WITH LESS

"We believe there's a better, healthier way to feed our cities: increasing access to fresh, pure, sustainable produce, grown as close as possible to people," says Erez Galonska, co-founder and CEO of Infarm. In September 2021, Infarm raised $170 million in a funding round – taking the total it had earned from investors to more than $300 million. It's also working with some of the world's biggest retailers, including Marks & Spencer in the UK, Kroger in the US, and Albert Heijn in the Netherlands, to bring Infarm-grown produce onto the shelves of supermarkets.

> "Vertical farming allows fruit and vegetable production to grow at exponential rates without wiping out forests."

NATE STOREY

Co-founder and chief science officer, Plenty

"We are growing salads, herbs and leafy greens, and will soon be launching varieties of mushrooms," says Infarm chief impact officer Sudhanshu Sarronwala. "We are also running tests with strawberries and tomatoes." In all, the company offers around 75 different products grown in its cloud-controlled farms that began as a test in Galonska's Berlin apartment in the early 2010s.

"Each of our modular farming units can produce 500,000 plants per year, which is the equivalent of a soccer pitch-worth of farmland on a footprint the size of your living room," says Sarronwala. The company claims to use 95% less land and 95% less water than traditional farming – all while cutting down food miles by 90%. (Landau, for his part, believes such figures are "a little ambitious", instead saying water savings are likely closer to 60–80%.)

An Infarm location uses five liters of water per kilo of grown food, compared to around 322 liters per kilo for traditional vegetable farming. "We already helped to save 60,000 square meters of land and 60 million liters of water, constantly working on driving towards even higher efficiency," Sarronwala adds. By knowing precisely how much water is needed, computer-controlled systems can drip-feed plants when required to ensure maximum growth.

The main challenge for the industry is lowering operational costs, says Landau. "Labor is a big one; energy is a big one. Getting the unit cost [of the finished produce] down to a level that the average consumer can afford and would purchase is a challenge."

SOME WAY STILL TO GO

So too is crop diversity. Vertical farming in some fashion has been around since the 1970s, but has long focused on microgreens and herbs, only recently moving to small lettuces and the like. "Science still has a long way to go before we can grow everything indoors," admits Plenty's Storey. "We have proven that we can grow leafy greens, and we are starting to grow other fruits and vegetables. However, it will take many years before we can grow all of our crops indoors, such as stone fruit and nut trees."

Some of the key concerns are how to replicate the inexplicable, intricate way nature works in a controlled, tech-enabled environment. "Issues such as pollination, disturbance, and delivering the right light spectrum can change from crop to crop," says Storey. "These things have to be researched for indoor growing to expand the crops we can grow."

Yet, just as it took centuries for early farmers to recognize the importance of crop rotation to boost their yields, and traditional intensive industrial farming spent decades eking out minor improvements, so vertical farming has to go on the same journey. Technology can help: "Our data analytics and machine learning review over 200 years of data annually to quickly iterate and improve farm yield, quality and efficiency," says Storey.

Europe and the USA are two key hubs for the vertical farming revolution, as is Asia, where Sinapore's Comcrops and Sky Greens lead the way. But the reality is that the industry currently requires so much energy that vertical farming isn't the solution to the food crisis that blights the developing world. "These operations are still energy-intensive," says Landau. "They tend to do well in colder climates because consumers there pay more for imported products."

As the initial hype around vertical farming cools off, we'll start to think about how to utilize its innovative technology more smartly, believes Landau. And that's where the sector will truly come into its own. "Vertical farming is just one tool in a larger toolbox to create stronger agricultural food systems," he says. "It's about understanding the regional and local context of the area you want to grow in and trying to determine what is the gap in that market." ■

PHOTOS: INFARM / DIEPHOTODESIGNER.DE; SPENCER LOWELL / PLENTY; PLENTY

DEEP IMPACT
AUTONOMOUS UNDERWATER VEHICLES ARE HELPING RESEARCHERS LEARN MORE ABOUT OUR OCEANS

Robots can help us learn more about ocean eddies, which impact marine life and the Earth's climate.

PHOTOS: SHUTTERSTOCK / JAPAN'S FIREWORKS

"FOR THE PAST FEW DECADES, ocean exploration has been highly inefficient," says Dr. Katy Croff Bell. "Things need to change." The American deep-sea explorer is a former MIT research scientist and founder of the Ocean Discovery League, which aims to expand marine exploration through accessible, low-cost technology. "We're having an enormous impact on the seas but still lack understanding of how complex and intertwined the various elements are. We need to avoid making the same mistakes in the oceans we've already made on land," says Dr. Bell.

The world of ocean exploration that Bell started out in would typically see huge research vessels carrying a crew of 30 to 60, plenty of heavy machinery and a hefty price tag: operating costs could quickly add up to tens of millions of dollars a year, restricting access to big-budget players like the US, Germany, UK, Norway, Japan and China. "This excludes a large percentage of the world – including most of the countries with a coastline," says Bell.

To make ocean exploration more accessible, scientists and engineers have started to develop small, unmanned vehicles that are more versatile, less expensive and easier to handle. The first to emerge (or rather, submerge) in the 1980s and 1990s were remotely operated vehicles (ROVs), tethered to a ship to transmit oceanographic data on depth, temperature and salinity. On-board cameras also enabled them to discover new species, volcanoes and shipwrecks.

ROVs were a real breakthrough but changed little in terms of cost and access to ocean exploration. According to Bell's research, these early ocean robots, which rely on a fully fledged research vessel to operate, have covered an area barely twice the size of London (3,140 square kilometers). "That means there's still 99.9995% of the seabed to go," she says.

Fortunately, engineers and scientists are constantly working to further shrink, enhance, diversify and lower the cost of instruments for ocean exploration. Autonomous underwater vehicles (AUVs) operate untethered from a ship and can ↘

↘ roam freely on designated missions without being directly controlled by an operator. These self-propelling robots come in various shapes and sizes. Some are able to explore the deepest regions of the oceans, collecting high-resolution data that are first stored inside the vehicle then later analyzed by researchers when the AUV has surfaced.

Drifter and glider robots come without their own propulsion and rely on ocean currents. They can travel thousands of kilometers, sometimes for years at a time, and are cheaper and easier to maintain than ROVs. Gliders are mostly used in remote locations to collect data on things such as temperature, salinity, currents and fish behavior.

VERSATILE AND SMART

Robots don't just explore beneath the surface of our oceans, though. Unmanned surface vehicles (USVs) use solar panels and sensors to measure weather patterns like wind and waves. More sophisticated tools, like the ones engineered by US company Saildrone or Ireland's XOcean, include USVs to map the geography of the ocean floor or scan for ship and plane wreckages using sonar, acoustic sensors, cameras. In 2018, Ocean Infinity, another US-based company, covered 112,000 square kilometers of ocean floor in just three months during a search for the missing Malaysian Airlines flight MH370 in the southern Indian Ocean.

Indeed, there is a variety of ways in which methods initially developed for ocean exploration can be applied to other tasks. Military and space agencies have partnered marine scientists since the beginning of robotic ocean exploration in the 1990s. "Learning about underwater navigation, communication and visual mapping, as well as energy issues, are the very topics you deal with when exploring Mars or even extra-terrestrial oceans millions of kilometers away," says professor João Sousa. The head of the Underwater Systems and Technology Laboratory at the University of Porto has teamed up with the Portuguese Navy and NASA for several projects. Other non-oceanographic uses include mineral resource mapping, surveying oil and gas sites or mine-hunting.

Saildrone (below) captures data for climate, mapping and maritime security. The penguin-inspired form of the Quadroin (right) allows it to efficiently explore underwater.

> "We need to avoid making the same mistakes in the oceans that we've already made on land."

DR KATY CROFF BELL

Marine explorer and founder of the Ocean Discovery League

AUV engineers are paying increasing attention to nature when designing their robots. "Bionics and biomimicry open up an array of possibilities to improve AUV performance," says Burkard Baschek. While heading Germany's Institute of Coastal Ocean Dynamics at the Helmholtz Centre Hereon in Geesthacht, Baschek partnered with Berlin-based company EvoLogics to develop an AUV that resembles a penguin.

After years of extensive research, the super-streamlined Quadroin, a 3D-printed, self-propelled robot, is able to measure ocean currents, called eddies, that other researchers have struggled to capture – despite their scientific importance. Eddies impact all marine life as well as our climate. "They are vital to the production and transportation of phytoplankton in the ocean – a key contributor to Earth's atmospheric oxygen. Every fourth breath humans take depends on eddies," says Baschek, now director of the German Oceanographic Museum. Because they are very small – between 10 and 1,000 meters in diameter – and decay in a matter of hours, traditional research methods have so far proved impossible. A conundrum that is now solved by the Quadroin robot.

The artificial penguin is far from the only AUV that copies nature. Researchers at the University of California San Diego have developed a squid-like robot equipped with a camera, while a team at Zhejiang University in China has designed a fish-like robot that has already explored the Mariana Trench more than ten kilometers below sea level.

And just like animals, these robots needn't operate alone. Soon, a third Quadroin will be give Baschek a group of robo-penguins that can communicate with each other by sending and receiving chirping signals like dolphins.

Portuguese marine expert João Sousa also sees the benefit of this approach, but adds: "A mere swarm is not enough." He is convinced that a hierarchical planning and execution control architecture including networked underwater, surface and air vehicles could be even more successful. Sousa has been working with octocopters and mini-airplanes equipped with video cameras, multispectral cameras and gas sensors, as well as acoustic modems for communication with submerged AUVs.

But it isn't all about "just" creating robots to dive deeper, roam for longer or collect even more data. The likes of Katy Croff Bell want to enable more people to find out more about the ocean. This requires low-cost technology and expanded infrastructure.

"My vision is to make the deep sea accessible to as many countries and communities as possible," she says. "Only by working with a global community of explorers to create efficient, equitable systems can we truly discover and understand the importance of the deep ocean." ■

PHOTOS: JENN VIRSKUS / SAILDRONE, HEREON / FLORIAN BÜTTNER, KATY CROFF BELL; ILLUSTRATION: ULI KNORZER

JAMES BELLINGHAM ON INNOVATION AND ENTREPRENEURSHIP

James Bellingham is executive director of the Institute for Assured Autonomy at Johns Hopkins University. Prior to that, he worked at MIT and the Woods Hole Oceanographic Institution. After more than 40 years in ocean exploration, he says the central idea of innovation and entrepreneurship has significantly changed. "Research organizations once saw their students and publications as their key contribution to innovation. Like the academic ivory tower, every now and again a few new ideas would be pushed out the window." Today, the model has shifted from the ivory tower to the beehive: "Talented folks [the bees] are now 'pollinating flowers' by collaborating and creating new industries before coming back to their hive." Founding start-ups within the so-called "new blue economy" has become the vector for moving projects from the lab to broader application, he says.

An autonomous parcel delivery robot on campus at KAUST.

BUILDING THE ROBOTS OF OUR DREAMS

How the King Abdullah University of Science and Technology is shaping the future

BY TONY CHAN AND ERIC FERON (KAUST)

WE ARE SUPPOSED TO be living in the age of robots, yet we are still far from the days of robots looking, behaving, thinking and empathizing like humans. As we fly across the ocean, walk into our homes, drive across the country, we wonder: Where are the robots of our dreams? The dreams of our youth? Where are the robots hiding? Are they real?

But subtle shifts are taking place. Think about our cars today and those of our parents: What a change! Our parents were the "consciousness" of their cars, constantly checking everything from tire pressure to engine condition. Today, our cars have their own consciousness, able to tell us when something is wrong, both inside and out. They even take care of us, gently adjusting the temperature, and are always ready to cushion us from an unexpected accident.

KAUST researchers have developed CoraPrint, a 3D-printing technique that could help coral reef restoration.

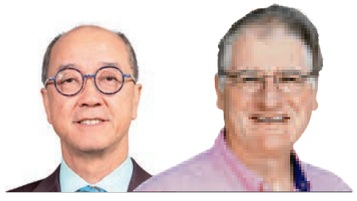
CREATING A BETTER WORLD

At Saudi Arabia's King Abdullah University of Science and Technology (KAUST), when we look up at the night sky, we can often see a steady blinking light – the drone used by the people in charge of security at KAUST. We then remember the same drone is used to survey the fragile coral of our Red Sea coastline and we feel reassured: Yes, robots are everywhere. They don't yet look like the ones in our dreams, but they are here and, importantly, they are here to help.

Which isn't to say that all KAUST's robots are fully "there" yet. The automated shuttles and parcel delivery vehicles running across the campus can sometimes look premature and imperfect, like the Wright brothers' Flyer did in 1903. Yet we know that KAUST, by making itself a beta test site for robotics technologies, is part of a giant experiment whose outcome will be a better, more convenient existence for us all. Maybe our world-class cybersecurity specialists, or their students, will find a vulnerability nobody expected? Maybe our humble gardeners will think of unexpected applications for these vehicles?

> "Robots are everywhere ... and, importantly, they are here to help."

PHOTOS: KING ABDULLAH UNIVERSITY OF SCIENCE & TECHNOLOGY (4)



TONY CHAN AND ERIC FERON

Tony Chan (left) is the president of KAUST; Eric Feron is a professor in electrical and computer engineering at KAUST.

FROM CORAL TO TRAFFIC

Inside KAUST's buildings, robotic technology is everywhere. Many of our biological assets are manipulated automatically by robots. The 3D printers we operate and build can create live coral reefs to restore our marine environment or print parts for other robots such as actuators, sensors and, soon, circuits. And sometimes they even print parts for themselves, just like living things do.

The work of KAUST's start-ups covers many areas of our lives. FalconViz, for example, uses drones to build maps of the campus. These will also be used to design autonomous urban traffic control systems allowing urban air, ground and sea mobility vehicles to link research and residential communities along the Red Sea.

KAUST is a robotic development ecosystem. Individual efforts, combined with economic innovation and investment, build on each other to create an ever-expanding set of robotic components and systems. There are also valuable interactions with the wider international scientific community, each helping pave the way for a robotic future to help humans. ■

CALL TO IMPACT

1. Most current robots may not look like they do in science fiction, but things are changing fast.
2. KAUST is home to research that will provide a better, more convenient existence for all.
3. It is also part of a global ecosystem that continues to drive innovation.

RADARS: A DEXTEROUS FORM OF ROBOTICS

Tackling everyday issues with this versatile technology.

BY ABDULAZIZ SIRAJUDDIN

mmWave radar is successfully reducing traffic congestion on Riyadh's busy streets.

PHOTOS: AERIALPERSPECTIVE WORKS / E+ / GETTY IMAGES, FII INSTITUTE

OBSERVING HOW PEOPLE commute can provide a variety of revealing insights. By analyzing the vast amounts of data collected from tracking traffic movement in a large modern city, decision-makers can gather invaluable information on how to improve urban planning.

This inspired a recent research project at the FII Institute, initially focused on traffic flow optimization but ultimately going on to address a number of needs involving movement tracking.

Most modern cities have undergone decades of complex transformation to reach their current structure. The level of development is influenced by a city's location, wealth, governance, inhabitants and culture. Many Western cities have experienced slow and sustained change, benefitting from multiple industrial revolutions. At the other end of the spectrum, evolution in cities lacking the same levels of wealth and/or good governance has been slower and often non-linear when compared with contemporary technological advancement.

However, there are outliers to this trend; cities that discovered sudden prosperity during the 20th century, often due to the discovery of natural resources. Riyadh, the capital of Saudi Arabia is one such city. The discovery of fossil fuels in the country has led to massive prosperity for the city and its inhabitants. One by-product of this shift has been omnipresent traffic congestion in Riyadh over the last two decades.

> "Radar technology has seen huge recent growth in civil applications."

ABDULAZIZ SIRAJUDDIN
Idea curation specialist, FII Institute

FROM TRAFFIC TO PUBLIC HEALTH

Now, radars are helping to tackle the problem. Earlier often led by military interests, radar technology has seen huge recent growth in civil applications, partly due to autonomous technologies.

One type of radar that has evolved significantly is millimeter wave (mmWave) radar. By combining this technology with the ability to conduct predictive analytics from large sets of data in near real time, an FII Institute team recently developed a way to ease traffic congestion in Riyadh.

We deployed mmWave radars at traffic lights on all intersections in the city to capture data on things like traffic speed and volume. Over time, this data revealed congestion patterns on different streets. Eventually, we were able to predict traffic congestion and manipulate the right of way to optimize traffic movements across the city and minimize tailbacks.

As this solution was being developed, the world was struck by the outbreak of Covid-19. Our team, leveraging the utility of mmWave radars, saw this as an opportunity to exploit the wide spectrum of frequencies the radars had by design. With radars, large-range frequencies can detect motions of big objects at a greater distance, whereas short-range frequencies are able to sense smaller objects and more minute motions. By tapping into the shorter range frequencies, we developed a crowd management solution to track pedestrians and ensure social distancing in public areas.

And that wasn't all. The tool's utility was further demonstrated when we explored how short a frequency mmWave radars can truly operate on. The team developed an algorithm enabling medical professionals to detect possible Covid-19 infections by using radar to gauge heart-rate increase and lung disturbance - the earliest symptoms of potential infection.

EVERYDAY INTEGRATION

While all three solutions showed tremendous promise as pilots, the pandemic played a decisive role in shifting priorities towards the Covid detection prototype. The technology was further developed, tested and validated, before being purchased by the King Abdullah International Medical Research Center, a prominent regional hub for biomedical and clinical research.

As these projects show, radars are an excellent example of dexterous robotics: a change in frequency can unearth new applications. With the rapid improvements in autonomous technology, radars are set to become increasingly integrated into our everyday lives. It will be exciting to see where this technology will head over the next few years. ■

HOW DO ROBOTS SEE?

The mechanics of robot vision are similar to animal vision, relying on detectors (eyes) and processors (the brain). Recent technological advances are now giving robots better vision and better decision-making capability than ever before, enabling them to carry out increasingly complex tasks.

THE POWER OF INVISIBLE LIGHT

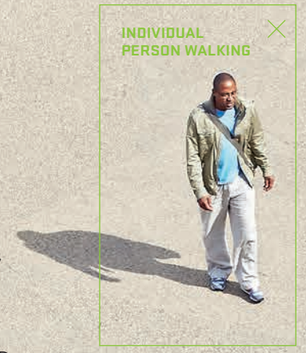
While human vision is restricted to a narrow band of the electromagnetic spectrum, machines can detect a wider range of frequencies and gather additional information. Autonomous cars, for example, use LiDAR (Light Detection And Ranging) devices, which send out invisible infrared light to map the distance to surrounding objects. Or thermal imaging cameras, which turn infrared radiation into visible images. The latter are now being put to use in autonomous search-and-rescue drones. David Schedl, professor of visual computing at the University of Applied Sciences in Hagenberg, Austria, has developed an algorithm that selectively removes trees from a drone's field of view. This enables the robot to effectively see through a forest, making casualties on the ground clearly visible. The drones were successful in locating and identifying about 90% of hidden human targets under a variety of adverse conditions.

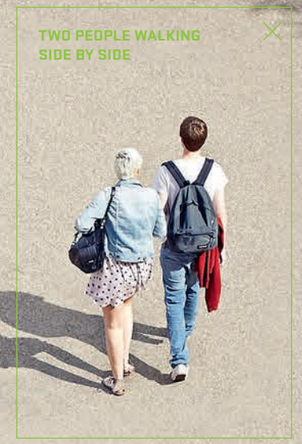
COLORS OF THE RAINBOW

Spectroscopic imaging enables the remote detection and identification of materials, whether solid, liquid or gas. A spectrograph records the amount of light emitted by an object across a spectrum of colors, recognizing the unique signatures of materials. This has traditionally been a slow process, making it unwieldy for use on a robot, but a recent development form the University of Colorado may change that. "Our new system can measure a spectrum in mere micro-seconds," claims researcher Scott Papp. The team has developed a dual-comb spectrometer, using two laser sources passing through a microchip wave-guide. The resulting multi-color output – similar to the rainbow of light pro-duced by a prism – is called a supercontinuum. This allows onboard chemical analysis in dynamic envi-ronments such as disaster management or quality control on a production line.

JOSTLING IN A CROWD

Robot vision is critical in the safe and efficient operation of swarmbots – multiple independent robots each working as part of a team. Not only do these machines need to navigate their environment, they must avoid collisions with each other. Taking a cue from the schooling behavior of fishes, researchers at Harvard University have found a simple way to let swarming robots detect each other without needing continual 3D position monitoring through GPS and radio. By equipping each bot with a simple flashing LED and inexpensive light detectors, swarmbots can make schooling decisions based on passive visual observations. Potential uses include environmental monitoring, infrastructure inspection and surveillance.





SPEED IS OF THE ESSENCE

High-speed drones are already commonplace, and autonomous robots driven by advanced AI and deep learning are becoming standard. But combining speed and autonomy in a single machine remains challenging due to the huge volume of data. To date, fast navigation has remained in the realm of human pilots. Now, Dr Antonio Loquercio of the University of Zurich, Switzerland, has developed a new approach. His program creates a 3D point cloud representation of the terrain and calculates trajectories, which are assessed by a policy program using real-time sensory data. Drones operating this system averaged speeds up to five meters per second while navigating unfamiliar environments such as dense forests, snow-covered ground and collapsed buildings – more than twice the speed of comparable autonomous drone navigation methods.

UNDERGROUND EXPLORATION

One of the most challenging environments for both robots and humans is underground. Quadruped walking robots and aerial drones each claim some advantages in these settings, and successful missions in real-life emergencies may rely on a combination of the two. Professor Kostas Alexis of the Norwegian University of Science and Technology's Department of Engineering Cybernetics leads the international Cerberus project, which deploys just such a combination to explore and chart mines, caves and tunnels. A real-time 3D map of their interiors is generated by continual scanning from a rotating laser in the "nose" of the bots. Radio communications are unreliable underground, so each bot stores its own topological data until it can share it with a central communications hub. From there a complete 3D map can be created and continually updated, allowing resources to be directed to where they will be most useful.

PHOTO: MICHAEL BLANN / STONE / GETTY IMAGES

ICONS: THE NOUN PROJECT/ FATAH ISLAM NARAPPI/ MAT STEVENS/ FAHMI/ SOPHIA BAI

THE FUTURE OF LOGISTICS TAKES FLIGHT

How drones are revolutionizing humanitarian supply chains

BY FRANCISCO SERRA MARTINS

The network has cut waiting times for lifesaving medicines."

FRANCISCO SERRA MARTINS
Idea curation manager, FII Institute

IN MOZAMBIQUE, a network of unmanned delivery drones is supplying hospitals with medicine and other vital supplies to reduce maternal mortality in the conflict-affected province of Cabo Delgado.

Launched in 2020, the network has cut waiting times for lifesaving medicines and helped create a greener, more reliable infrastructure for transporting medical supplies over long distances. The delivery network is the first of its kind in the country and aims to establish a national infrastructure for transporting blood transfusions and pathology samples via unmanned aircraft systems (UAVs). The drones, which also transport Covid-19 supplies, can carry medicine, blood, and other medical supplies up to 800 kilometers to remote and off-track locations. They operate over 4G and 5G networks, while satellite communication networks help to extend their range beyond the horizon.

Associação de Combate e Prevenção do Covid-19 (APPCC 19) is run by a consortium of organizations in Mozambique and the Community of Portuguese Language Countries (Comunidade dos Países de Língua Portuguesa; CPLP). Drone logistics non-profit Dove Air is leading the group, and European drone manufacturer UKR Spec Systems is providing drones capable of carrying a 19 kilogram payload 400 kilometers. This ensures they meet all the provincial vital blood delivery requirements.

BLUEPRINT FOR UAV LOGISTICS

Crucially, the project has received operational authorization from the Mozambique Civil Aviation Institute. This means the consortium can operate within coastal humanitarian flight corridors to validate the capabilities of drone logistics networks. Nuno Serra, COO at Dove Air, says the project will "provide a blueprint for UAV-based logistics to be tested in other areas of Africa and around the world."

According to the consortium, more than 40,000 deliveries have already been made, a third of which are on-demand deliveries of lifesaving medical aid.

Funded by consortium APPCC 19 and a grant from Serra de Estrela Investments Ltd, a family office philanthropic trust, the project is part of a broader effort to explore how drones can solve equitable healthcare access.

According to the consortium, its drone delivery system will ensure faster turnaround using autonomous deliveries that can be processed at any time. This provides greater flexibility, helping to meet the supply and processing needs of medical centers around the country. For the project's next stage, the consortium will expand the corridor in which unmanned UAVs can operate safely and integrate further into manned aviation airspace.

The consortium aims to have fully operational routine medical deliveries by the end of 2022. ■

PHOTOS: DOVE AIR, FII INSTITUTE

CALL TO IMPACT

1 Drones have cut waiting times for vital medicines in Mozambique.

2 Autonomous delivery offers greater flexibility for medical centers.

3 The project offers a blueprint for global UAV delivery networks.

DRONES CAN SOW SEEDS OF HOPE

Forests and their ecosystems are crucial to life on our planet. Yet deforestation has wiped out hundreds of millions of hectares of woodland in recent decades. Now, drones are helping to restore valuable biodiversity and natural carbon capturing.

"DEFORESTATION and forest degradation continue to take place at alarming rates," reads a 2020 UN report titled The State of the World's Forests. It reveals that from 2015 to 2020, the rate of deforestation was around 10 million hectares a year, an improvement on the 16 million hectares a year in the 1990s. Despite this relative progress, however, it is estimated that, since 1990, 420 million hectares of forest have been lost through conversion to other land uses – the equivalent of almost 600 million soccer fields.

Such numbers are staggering, and they lay bare the scale of the challenge the world faces if deforestation is to be not only stopped but reversed. There is, however, some hope. On the one hand, the world has never been so aware of the need to protect the natural environment. Indeed, at the recent COP26 climate summit, world leaders promised to end deforestation by 2030. And on the other hand, technology is now also playing a key role in reforestation.

One fascinating example is the use of drones to carry out the hard work of planting seeds. If successful, millions of new drone-planted trees could be central to future carbon sequestering and reducing the amount of CO_2 in the Earth's atmosphere.

> "I wanted to do something that captured carbon ... and made a dent in emissions."

GRANT CANARY

Founder, Drone Seed

IT'S SHOWTIME

The use of drones for reforestation is becoming increasingly popular, with Flash Forest working in Canada, for example, Lord of the Trees in Australia, and Marut Drones in India. The reasoning is simple: Drones have the potential to outdo humans in terms of efficiency when it comes to reforestation. It can take humans hours, days and weeks of hard, physical work to plant the seeds, while it takes a drone a matter of tens of minutes, depending on the size of the area.

Grant Canary founded US start-up Drone Seed in 2016, with the aim of making a significant contribution to reforestation efforts in the United States. "I wanted to do something that captured carbon out of the atmosphere and made a dent in carbon emissions," he says. The result is Drone Seed, a company that has recently raised $36 million in investments. It is a pioneer in post-wildfire reforestation and uniquely approved by the US Federal Aviation Administration to fly its 50 kg drones after wildfires, which can be devastating for forests. The 2021 August Complex fire in California, for example, destroyed 4 million acres, or 3 million American football fields.

Its reforestation works in three steps. First, a few weeks before seeding begins, they send out survey drones to create a 3D map of the proposed area. This, explains Canary, "captures several times more data than most self-driving cars." It includes, he says, something as small as "two-inch branches," or anything else that could knock a drone out of the sky. Step two is using the map to work out the optimum locations to provide the best chance of growth, while step three is what Canary calls "Showtime," during which two to five aircraft take off in swarms and fly preprogrammed routes. They drop their seeds, come back, get a battery swap, resupply, and set off again.

While Drone Seed is a for-profit company backed by venture capital, it is not the only model. In his role as Head of Engineering, Jürg Germann has led the team at the not-for-profit WeRobotics since 2018. In collaboration with a sister company, FlyingLabs Panama, in 2020 it co-led a project to demonstrate its unique seed ball "drone-optimized release system." The project examined whether drone technology could efficiently restore ecosystems in two communities in Panama's Central Provinces, Oeste and Coclé.

Each drone was adapted to carry approximately 800 20 mm seed balls per load, with 2,500 seed balls for each hectare of land. "It's highly automated," says Germann. "You load the system with the seed balls, launch the drone and it carries out the pre-programmed flight and releases the seed balls."

Each seed ball contains seeds about 5 mm in diameter, mixed with something like sand and typically some spices to deter predators. The balls are usually dropped from 30 meters above ground, though it depends on the project: To restore mangrove trees on wet coastal areas, the drones flew as low as 3 meters .

MEASURING SUCCESS

It will be some time before it is possible to truly gauge effectiveness in the form of new trees. Measuring success, says Canary, is like getting "the odds on blackjack," because you need to know who has got which cards, including the dealer. The analogy highlights that every situation is different, and whether the ground is arid or wet, for example, or with high predation. "Our job is basically to play blackjack with the seed vessels and to boost the probabilities in favor of the seed," he says.

Jürg Germann is also cautious about measuring success, but optimistic about the long-term efficacy of drones in helping reverse deforestation. The aim now, he explains, is that drones help to get us "to the point where we can say that with our restoration not only are we sequestering carbon but we are also increasing biodiversity." ■

PHOTOS: DRONESEED (2)

US start-up Drone Seed is already replacing forests destroyed by wildfires.

GLOBAL DISTRIBUTION OF FORESTS

The ten regions with the largest forest area (% of world's forest in 2020)

GREEN COVERAGE

More than 50% of the world's forests are in just five countries: China, the US, Canada, Brazil, and the Russian Federation. In total, forests cover around 31% of the Earth's land area, approximately 4.06 billion hectares.

VITAL FOR LIFE

Forests and their ecosystems are central to the way the planet functions, and without them the world would be inhospitable. They are home to millions of species, and are responsible for a huge portion of the world's territorial biodiversity.

AGAINST CLIMATE CHANGE

Equally significant is the role trees play in helping cool the planet by acting as "carbon sponges," taking CO_2 out of the atmosphere and subsequently combatting global warming.

CALL TO IMPACT

1. Forests are vital for life on Earth: they are home to rich biodiversity and act as an effective means of removing carbon from the atmosphere.
2. But since 1990, approximately 420 million hectares of forest have been lost to other land uses: the equivalent of almost 600 million soccer fields.
3. Drones are now proving an efficient way of sowing seeds to grow trees in certain areas.

Drones can quickly reach high-risk areas to capture valuable data, search for survivors or deliver aid.

PHOTOS: OLIVIA HARRIS / REUTERS, STUART MARTIN / PINPEP

THESE DRONES CAN SAVE LIVES

From fighting disease to responding to natural disasters, drones are now able to provide life-saving support in remote and dangerous areas.

WHETHER you call them drones, unmanned aerial vehicles (UAVs) or flying robots, remote air services are soaring. The global drone market is forecast to reach $41.3 billion by 2026, with medical logistics and search and rescue fueling that growth. The public safety drone sector alone is expected to reach $5 billion by 2030.

The big driver is affordability, with $1,600 the average cost of a commercial drone worldwide. While emergency services routinely fly UAVs costing 10 or 20 times that, it's a fraction of the cost of buying or flying manned aircraft.

These cost savings are key in leveling healthcare inequalities, too. Drones can reach regions poorly served by roads and hospitals, or cut off by disaster. Crucially, they do this without risking pilots' lives.

Now, drone projects are combining these advantages with new technology to transform healthcare and disaster response. From fighting disease to finding survivors, where there's a will, drones are forging a way.

1. FIGHTING DISEASE

WeRobotics moves mosquitoes. In 2018, its autonomous drones dispersed sterilized mosquitoes in Juazeiro, Brazil – one solution in the fight against Zika virus. The modified insects can't reproduce, reducing wild populations over time.

Now the socially minded tech lab is working with the World Mosquito Program. But the insects they're releasing in Fiji aren't sterilized; they're injected with a naturally occurring bacteria. Dr. Jürg Germann, WeRobotics head of engineering, explains that mosquitoes carrying Wolbachia bacteria are less likely to transmit dengue, Zika, chikungunya and yellow fever.

> "UAVs offer higher vantage points and safer access to high-risk environments."

GEMMA ALCOCK

Founder, SkyBound Rescuer

Drones as airborne mosquito taxis? It may sound paradoxical but it's hard to argue with the outcomes. In Juazeiro, drones dispersed sterile males across 20 hectares in about 12 minutes. The Aedes mosquito doesn't fly far, so a ground release achieving similar coverage would have needed two field staff, one vehicle and two hours. Drone release is cheaper, faster and not reliant on roads – useful in remote regions.

The team use multi-rotor drones to release mosquitoes at pre-programmed distances. These models are known for stability, but Germann says their built-in redundancy on motors, sensors and battery failure is especially important when flying over populated areas. Moreover, ↘

BVLOS: THE NEXT LEVEL OF THE DRONE REVOLUTION

→ **Most UAVs**, including those used by police and emergency services, navigate using Visual Line of Sight (VLOS). This means the pilot keeps visual contact with their craft at all times. It's the most accessible drone flight permission, but imposes distance and environmental limits; for instance, drones can't fly behind buildings and trees. Extended Visual Line of Sight (EVLOS) offers more flexibility, with a trained observer as intermediary to maintain visuals beyond the pilot's field of view.

→ **There's no requirement** for visual contact when flying Beyond Visual Line of Sight (BVLOS). Instead, drones fly autonomously or are monitored via ground control instruments and onboard cameras. This opens them up to greater distances and is central to the adoption of UAVs for medical logistics and search and rescue.

→ **BVLOS** is currently the most regulated and arduous category to qualify for, though this is likely to improve as nations race to create drone highways. These corridors of 5G-enabled airspace are being built around BVLOS, and are part of an emerging framework that should usher in faster flight permissions, making it easier to take to the skies.

↘ UAVs capable of carrying heavier payloads over greater distances no longer have to cost upwards of $10,000.

2. MEDICAL SUPPLY CHAINS

In October 2021, a commercial drone in the Indian state of Manipur completed a test flight to an island in the middle of Loktak Lake. It delivered ten doses of Covid-19 vaccine, managing the 15 kilometer run in 12 minutes – a journey that takes four hours by road and water. Eventually, drones like this will deliver up to 900 vaccine doses per flight.

It follows the Medicine from the Sky pilot project in the southern Indian state of Telangana, which launched in September 2021. Data from test flights will measure the feasibility of BVLOS (Beyond Visual Line of Sight – see box page 49) medical logistics and could eventually see drones delivering medicine, blood, organs and specimens.

This is already happening in Nepal, where half the population lives in remote, mountainous areas with poor access to healthcare – yet 70% of Nepalis are carriers of tuberculosis and 11 people die from the disease every day.

Flying Labs Nepal and WeRobotics are working with health agencies to bridge the gap, with BVLOS operations fundamental to their solution. DrOTS (Drone Optimized Therapy System) connects local health workers in remote locations with a diagnosis machine at a primary healthcare center. UAVs facilitate the collection and testing of sputum samples within half an hour, as opposed to two to three days by ground.

3. RAPID DISASTER RESPONSE

SkyBound Rescuer works with UK emergency services to optimize drone performance. Founder Gemma Alcock believes UAVs come into their own for disaster relief, "offering higher vantage points and safer access to high-risk environments." While the cost of helicopter support in the UK ($3,880 per flying hour) restricts its use to certain scenarios, drones can be implemented at every stage of disaster relief: planning, response and recovery.

One of the most critical uses is mapping. Drone footage is faster to process than traditional photography, and more detailed and up-to-date than satellite imagery. Alcock says that drones fly lower and slower than helicopters, capturing smooth, detailed and high-quality footage. They can also be programmed to accurately repeat flight paths, meaning that "high-risk areas can be mapped in minutes ... to deliver a better, more-informed response."

Now SkyBound Rescuer is partnering in Project XCelerate to complete the UK's first commercial drone zone, 40 miles east of London. Crucially, it will create a BVLOS corridor of unrestricted airspace for fully autonomous drones. For Alcock, this is essential to reducing emergency response times, allowing drones to reach an incident site ahead of operators. Ultimately, it paves the way for a network of BVLOS drones stationed around the UK, ready to be the emergency services' first eyes on the scene – and in a fraction of the time.

> "Drones often have optical and thermal sensors. But what about victims that are not visible to them?"

MACARENA VARELA

Fraunhofer Institute for Communication and Information Processing

4. SOUND, SEARCH AND RESCUE

"Drones often have optical and thermal sensors," says Macarena Varela, "but what about victims that are not visible to them? Victims that are under rubble or behind a wall, but are making sounds to be heard and rescued?"

Together with Dr. Wulf-Dieter Wirthand, Varela is developing a solution to give ears to drones and provide supplementary acoustic information to search and rescue (SAR) teams. Their listening device uses 32 microphones in a crow's nest array to locate and track sounds from the air. It couples this with artificial intelligence to filter out rotor noise and ambient sounds, and to distinguish distress signals – screaming, clapping and tapping – from other human sounds (including emergency responders and their vehicles).

The research dovetails with SAR's intention to leverage the time and cost savings of drone technology. Varela says that the solution could come to market within two years, but they are not yet affiliated to any company for further development and there is still work to do. The next step will be to double the size of the array and introduce microphones that can identify a wider range of noises from greater distances – a potential game-changer in situations where every second counts. ■

In remote areas like Nepal (far left) and Vanuatu, drones are being used to connect health workers with healthcare centers, drastically improving testing and delivery times.

PHOTOS: KIKE CALVO / AP IMAGES / PICTURE ALLIANCE, CHUTE / UN0264778 / UNICEF, MACARENA VARELA

CALL TO IMPACT

1 Falling costs are enabling drones to play a more active role in healthcare and disaster response.

2 Drones can quickly reach remote or dangerous areas without risk to pilots. They can deliver medicines, monitor disaster areas and find survivors.

3 More widespread approval for BVLOS operations will enable drones to cover much greater distances, expanding their effectiveness – and potentially saving more lives.

FII: ROBOTICS IMPACT REPORT 2022

THE HUGE POTENTIAL OF DRONES FOR GOOD

Drones can help people around the world to live their best lives, says Geoff Graves, advisor on humanitarian drone use and a former aid agency worker.

GEOFF GRAVES has worked for UN agencies, coordinated relief efforts in disaster zones and worked for Australian state and federal governments. He now advises international organizations, governments, NGOs and private sector partners, with a focus on how drones can help in disasters and development. In this interview, Graves discusses the "mind-bogglingly disruptive" potential of drones, what they can do in disaster or relief zones, and how they can deliver significant benefits in fields as diverse as health and natural resources.

How did you first get involved in drones?

Geoff Graves: I've held a pilot's license since I was 17 and have retained my interest in all things aviation. After working in emergency management in Sydney, Australia, I went to work for the UN, rebuilding infrastructure in Oecusse, East Timor, in 1999, after decades of conflict there. I've worked for Oxfam in Palestine, UN Agencies in Iraq, and AusAID, the late Australian Government Aid Program, as manager of humanitarian partnerships and programs. So I had humanitarian, evaluation and aviation streams to my career, which came together when UNICEF Australia asked me to evaluate an Australian aid program to deliver vaccines by drone to children in the Pacific nation of Vanuatu. I went to Vanuatu in 2018 and saw the disruptive potential of drones to overcome "the tyranny of distance." It's very expensive to move small things across mountains, along bumpy roads, over rivers and between islands. But it's super quick, super easy and super cheap by drone.

> **"Drones are the most efficient way of getting critical cargoes to hard-to-reach places: They're cheap and they don't risk pilots."**

So, this had a formative influence on you regarding working with drones?

Yes. I knew about drones, but I'd only really thought about them as being targets, carrying weapons or taking images. But the technology has changed so profoundly and quickly. Fuel technology has been revolutionized, motors are smaller and software has improved enormously. Smaller drones can now fly 100 kilometers on a battery the size of a brick. Larger drones can carry significant payloads hundreds of miles using hydrocarbons and even hydrogen. The other thing that's advancing strongly is the ability to fly accurately. Drones are the most efficient way of getting critical cargoes to hard-to-reach places: They're cheap and they don't risk pilots.

Why are drones so important in disaster areas?

Normally, you are operating with an absence of information. Phone lines are down or jammed but objective analysis is required to allocate the few resources that are available. A drone can take an immediate picture of the area and fly in situations in which a helicopter cannot. They can work effectively in fire and flood areas, too. If you want to spot fires or see which roads are flooded, don't send a valuable person in a truck, just send a drone. If a bridge is down, the drone will see it and report immediately. A drone can do an inspection along any critical infrastructure and even inside damaged buildings. Drones can also help in direct response, such as by dropping life rafts, lifejackets, radios or fresh water.

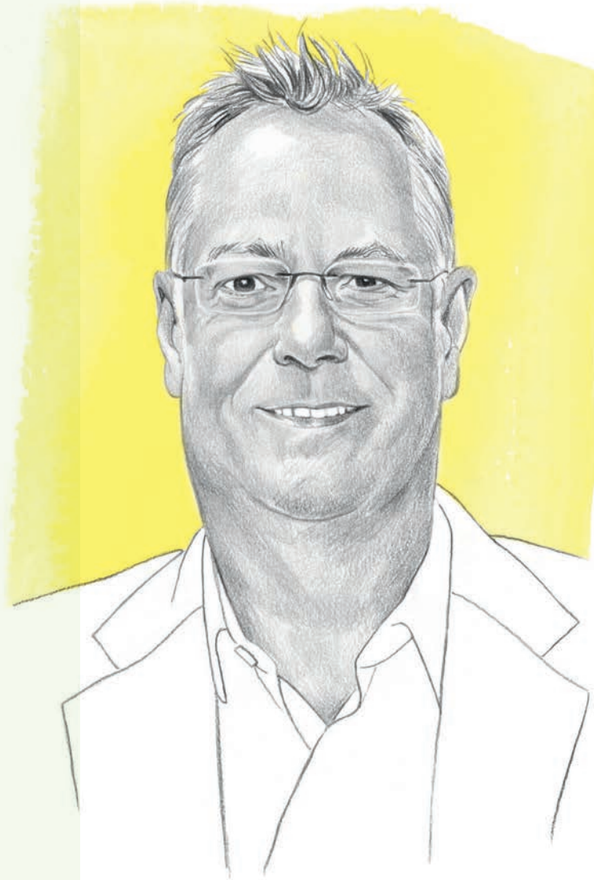


ILLUSTRATION BY ULI KNÖRZER

Where do you see further potential for drones?

We have yet to really begin exploiting the potential of "drones for good." On a hospital campus, drones can improve patient experience. You might have a clinic in one place, then a central pharmacy and a central pathology laboratory. But once patients have been seen, they basically wait. Wouldn't it be better for a patient to go in, get a sample taken, which goes directly to the pathology lab, where it's analyzed? The analysis goes straight to the doctor, who then makes a prescription, which is sent out by the quickest means possible to the patient before he or she walks out of the door?

Drones can also increase the accuracy of clinical diagnosis. Some remote clinics have to put samples into formaldehyde or other preservatives, which are then taken by van to a pathology lab. If you change to a model in which the sample is put into a test tube and sent immediately by drone to the pathology lab, the samples can be analyzed almost before they realize they've been removed from the body. You have a much better diagnostic accuracy if you don't have to deal with the artefacts of preservatives such as formaldehyde.

What are currently the main challenges for the drone sector?

Drone operations are limited largely by regulations. Governments are, quite properly, risk averse and want to prevent harm to their populations. Drone crashes could be quite damaging, so regulations lag behind the capacity of drones. But as evidence emerges about the relative safety of small vehicles moving in specially defined "drone airways" away from populations – versus, for example, large delivery trucks carrying one small parcel on busy roads with tired human drivers – people are beginning to see a wide potential range of positive outcomes. The US Federal Aviation Authority, the UK Civil Aviation Authority and the European Union Aviation Safety Agency, for example, are now starting to create regulations that lift some of the restrictions on drone operations.

What were authorities worried about in particular?

There were very clear aviation rules saying you couldn't fly over people, for example, and imposing limitations on what drones could carry. But drone manufacturers are demonstrating that their drones are safe, robust and have multiple fail-safes. If something does go wrong, the damage is limited.

And governments are starting to understand the benefits they can bring?

Yes. They now realize that the positives from drones increasingly balance any risk. And don't forget the impact of using drones instead of road vehicles. Every vehicle you take off the road decreases congestion and emissions, and increases safety.

So, what next for drones?

Drones are already inspecting oil tanker fuel cells, mapping mines, watching illegal fishing fleets and counting trees in the forest. They are reforesting deserts, fighting fires in skyscrapers and following fugitives without risky car chases. What I want to see drones do is enable people to live their best lives. The combination of environmental protection through reduced transport emissions, informed management of natural resources, and the improved responses to natural and man-made emergencies are within reach of today's technology. I'm just excited to see what will "take off" now. ■

GEOFF GRAVES

Geoff Graves is currently advising US start-up Valqari as it introduces its Drone Delivery Station. This is designed to make the "last inch" of the last mile of drone deliveries safe, secure, and smart. The automated solution enables any drone to drop off and pick up any payload, completely hands-free, 24/7/365.

ROBOTICS IN SURGERY
A CUT ABOVE

Intuitive's Da Vinci robot has pioneered minimally invasive surgery by enhancing surgeons' skills.

PHOTO: SPENCER LOWELL

SURGICAL ROBOTICS has come a long way since 1985, when the first robot-assisted surgery took place. Innovation has progressed from the first robotic arm, the PUMA 560, with limited reach, to the dynamic, all-encompassing Vicarious Surgical Robot, capable of precise incisions just over a centimeter long.

Demand for robotics in surgery is also at a high. In the UK, the number of robot-assisted procedures increased from 2,452 in 2013 to 10,067 in 2019 - a rise of more than 400%.

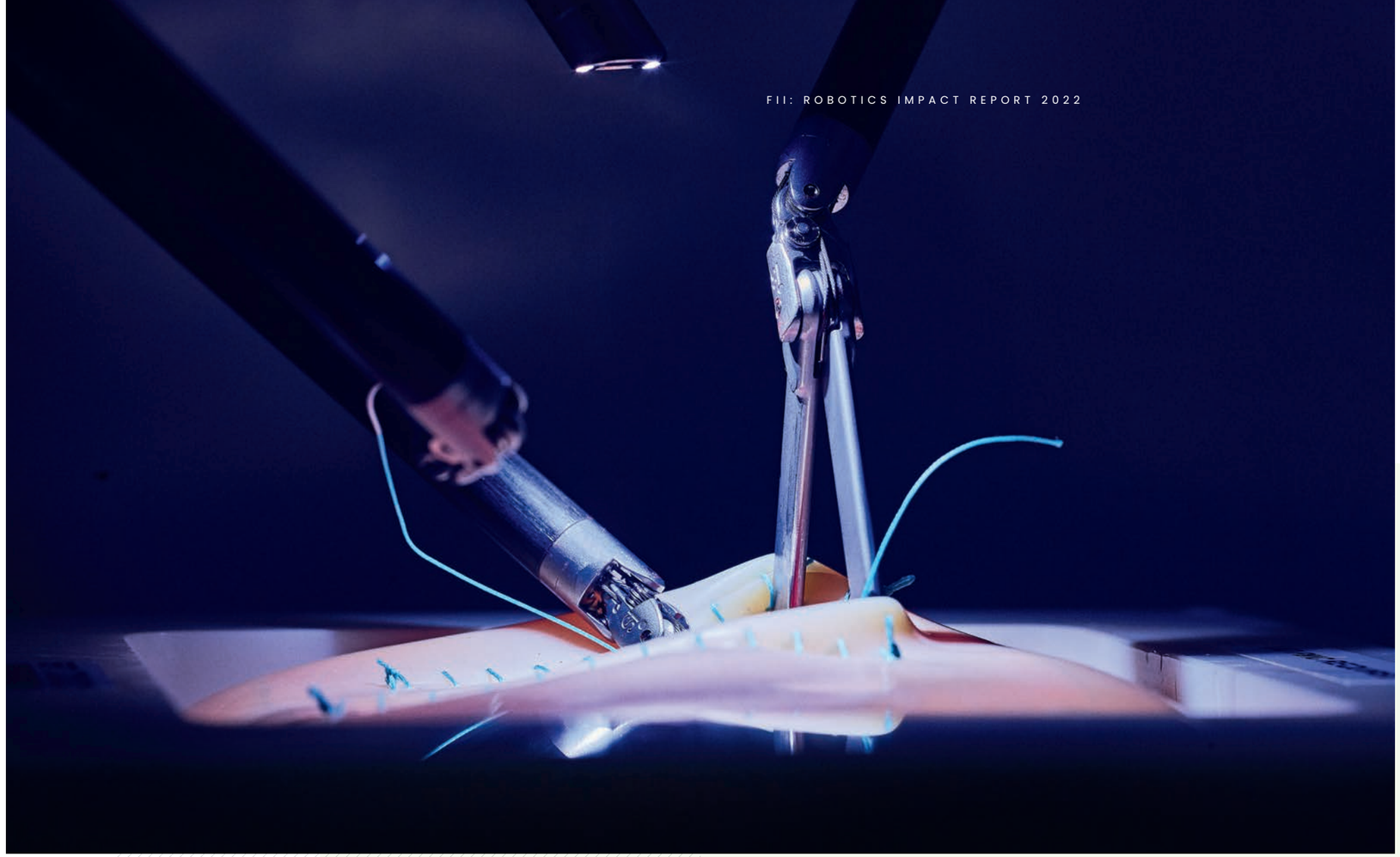
One trailblazer in this field was the Da Vinci robotic surgery system – the first all-encompassing robotic surgery system to be approved by the U.S. Food and Drug Administration (FDA) when it was introduced over 20 years ago. The "Endo-wrist" features of Da Vinci's operating arms replicated the movements of a surgeon, improving accuracy in smaller operating spaces.

Though historically more prominent in developed countries in North America and Europe, robotic surgery is also now becoming popular in the Asia Pacific region and South America. In Asia Pacific, market growth is driven by large populations and increased funding for medical robot research. In South America, it has gained recognition in countries such as Brazil, Chile, Uruguay and Argentina in the pediatric surgical world.

For women in the United Kingdom, Endometriosis is the second-most common gynecological condition, affecting one in ten women of reproductive age. It develops by forming growths of endometrial tissue in the ovaries, fallopian tubes, pelvic walls, bowel, ureters and the bladder. It also takes, on average, more than seven years for a woman to receive a diagnosis.

Traditionally, treatment options for mild symptoms include pain killers as a stand-alone solution or taken in combination with hormonal agents such as the oral contraception pill. For more severe symptoms, surgery is often the next available option, but absolute precision is required.

Robot-assisted procedures are one of the developments that will make the greatest impact on surgery.



Technological advances mean robots can now make incisions just milimeters long, speeding up recovery times.

CALL TO IMPACT

1 Surgical robots are now capable of making highly precise incisions just millimeters long. This can help surgeons carry out quicker, less invasive operations.

2 Traditionally more prominent in developed countries, demand is now rising in Asia Pacific and South America.

3 However, technology costs remain high and Covid-19 has hit healthcare budgets around the world, which is restricting adoption.

4 More mobile, affordable options are beginning to emerge but remain at an early development stage. Technology from other sectors, such as manufacturing, could drive further innovation and make adoption more scalable.

↘ IMPECCABLE PRECISION

Liverpool Women's Hospital acquired the Da Vinci X Robot to achieve exactly that. According to the hospital, the robot provides magnified and more stable 3D vision and greater maneuverability of surgical instruments, leading to "impeccable precision" during surgeries.

The result of using robotic-assisted surgery for deep infiltrating endometriosis is not only improved precision, it also shortens the length of operating time, lowers blood loss and likelihood for blood transfusion, lowers the rate of conversion to open abdominal surgery, and means less tissue trauma and less postoperative pain for the patient.

Manou Manpreet Kaur, consultant gynecologist at Liverpool Women's National Health Service, says that robot-assisted surgery could have positive impacts for other gynecological conditions: "for example [those] requiring a complex hysterectomy, which could be for benign reasons such as a fibroid uterus, or for womb cancer, or for women having recurrent miscarriages or preterm birth."

A growing, aging population, chronic conditions and the rising prevalence of neurological and orthopedic diseases is continually pushing innovation further. The demand for minimally invasive operations also means increasing calls for more advanced healthcare infrastructure. In India, for example, some 70% of surgeries are still performed as open procedures.

Medtronic is one company addressing the matter. In September 2021, Chennai-based Apollo Hospitals Group carried out Asia Pacific's first clinical procedure using Medtronic's Hugo, a portable and modular robot-assisted surgery system that pairs with a 3D HD vision surgical console. Medtronic also recently opened its first Surgical Robotics Experience Center in the Indian city of Gurugram, with the aim of training clinicians in India on its robotic technology.

THE ISSUE OF COST

Even with the growth surge in robotic surgery, there are still constraints. Infrastructure costs remain high and Covid-19 has put a serious dent in many healthcare budgets. According to the American Hospital Association, the pandemic has so far cost hospitals in the United States $202.6 billion. In the UK, the figure also runs into billions of pounds. Additional strain on health systems has also meant that front-line workers have faced different priorities, shifting focus away from procedures to treating patients in Intensive Care Units (ICUs).

One company believes it has found a solution to some of these issues. Backed by Bill Gates, the American Vicarious Surgical Robot is not only innovative with its freedom of movement–it looks to address the "prohibitive costs of adoption, limited mobility and capabilities in the body and required space."

Founded in 2014, Vicarious Surgical is made up of Adam Sachs, Sammy Khalifa and Dr. Barry Greene. Its surgical robot has received Breakthrough Device Designation from the Food and Drug Administration, and the company has gone public on the New York Stock Exchange.

Focusing on abdominal surgical procedure – only 3% of addressable abdominal procedures are performed with robotic techniques worldwide—its miniature robot enters the patient's belly through a single 1.5 mm incision (smaller than a dime) and can move in all directions. It is also mobile and easy to set up and take down. And it costs less, too – according to Sachs, the cost is five to ten times lower than Intuitive's Da Vinci. Not currently on the market, Vicarious Surgical plans an imminent roll-out of its robot, starting with hernia repairs, before moving on to gynecology and biliary procedures.

ADAPTING INNOVATION

Looking ahead, innovations from other sectors, such as manufacturing, could be used in the medical and surgical industry over the coming decade. In the United Kingdom, researchers at the University of Nottingham have been working on how to transition its COBRA robot from engine repair and inspection to medical uses.

Long and thin, COBRA can "slither" through small spaces as well as move around tight bends in sensitive environments. Comprising four different metal probes, each up to five meters long and each with a different repair tool, a sensor and a camera at the tip, the robot is a one-of-a-kind design. Thanks to an Engineering and Physical Sciences Research Council impact accelerator project, COBRA is now being adapted for throat cancer and injury surgery.

Observational studies have shown that robotic-assisted surgery has a positive impact on throat cancer patients, including higher survival rates and a reduced need for chemoradiation therapy. Preliminary tests with the modified COBRA robot have shown that it can safely access hard-to-reach parts of the back of the throat via the mouth – locations that currently cannot be accessed without highly invasive procedures.

According to the Royal College of Surgeons in the United Kingdom, minimally invasive robot-assisted procedures are one of the developments that will make the greatest impact on surgery over the next 20 years, particularly as the barriers of expense and accessibility continue to fall. ■

PHOTOS: SPENCER LOWELL

ROBOTICS CAN CREATE A NEW ERA OF HUMAN PROSPERITY

FII-I has three pillars to deliver its mission: THINK, ACT and XCHANGE

1 FII-I THINK
Identify societal challenges and current inhibitors. Curate the brightest ideas to address societal issues

2 FII-I ACT
Catalyze innovation and initiatives by mobilizing partners and resources

3 FII-I X CHANGE
Create platforms for live discussions on the future of humanity. Share knowledge, stories and publications with different stakeholders

THE RELATIONSHIP between humans and robots has evolved in a compelling manner. Robots have long presided over the collective imaginations of previous generations. Machines, the predecessors of robots, played a key role in elevating human productivity but were accorded a mixed reception from humans. The first Industrial Revolution was a mega-scale introduction of machines, in which they quickly became viewed not as a complement to human labor but its competitor. Rapid industrialization required large swaths of labor to be funneled into factories and keep up with the enormous productivity unlocked by machines.

In more recent times, as science and, by extension, technology, has witnessed an unparalleled pace of advancement, this dynamic has transformed. The introduction of artificial intelligence has seen machines evolve into dynamic robots. For the first time in history, there is a possibility that artificial intelligence (AI) will exceed that of humans.

While science fiction has run wild with ominous projections of robots taking over, scientists and entrepreneurs are working to incorporate them into human life in a complementary manner. Robotics has the potential to relieve humans of unwanted labor, engender new jobs, unlock tremendous levels of productivity and efficiency, and usher humanity into a new era of prosperity.

ROBOTICS MISSION STATEMENT

Robotics has been a core focus for the FII Institute since its establishment a little over a year ago. The field is becoming increasingly present in everyday life and assimilation is projected to accelerate in the coming decade. The industries expected to be most affected include transportation, logistics, agriculture, and healthcare.

The FII Institute has developed an AI and Robotics Roadmap to help this wide variety of technologies make a positive impact on humanity. Our investment arm, ACT, also prioritized robotics in its first set of investments. All four of the start-ups the Institute has invested in feature robotics as an integral part of the value proposition, and cover industries like transportation, sustainable farming, and healthcare.

With the publication of this report, the FII Institute renews its commitment to covering the field of robotics, as the technologies involved become increasingly integrated into our day-to-day lives. ■

THE FII INSTITUTE

is guided in all it does by a strong purpose, vision and mission.

PURPOSE
"Enabling a brighter future for humanity"

VISION
"Empowering the world's brightest minds to shape a brighter future for ALL, and with ALL"

MISSION
"Curating and enabling ideas to impact humanity sustainably"

PHOTO: ADOBE STOCK, FII INSTITUTE

SOURCES

Overview of key sources used for this report

GLOBAL ROBOTICS

Boston Consulting Group
Robotics Outlook 2030

World Economic Forum
The Future of Jobs

IDTechEx

International Federation of Robotics

CLIMATE

Food and Agriculture Organization of the United Nations
The State of the World's Forests

American Scientist
The Robot Ocean Network

HEALTHCARE

European Parliament
Robots in Healthcare

Nature journal
Your Robot Surgeon Will See You Now

AGRICULTURE

Lincoln Institute for Agri-Food Technology

AgFunderNews

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Transforming Agriculture Through Digital Technologies

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PUBLISHER
Future Investment Initiative Institute
3884 Alakheel
District Unit 9
Riyadh 12382 - 6613
Kingdom of Saudi Arabia

CONTACT
For clarifications and inquiries, kindly email:
info@fii-institute.org

EDITOR
Geoff Poulton

“ROBOTS ARE EVERYWHERE. THEY DON’T YET LOOK LIKE THE ONES IN OUR DREAMS, BUT THEY ARE HERE AND, IMPORTANTLY, THEY ARE HERE TO HELP.”

TONY CHAN AND ERIC FERON
(KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY)