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PIONEER

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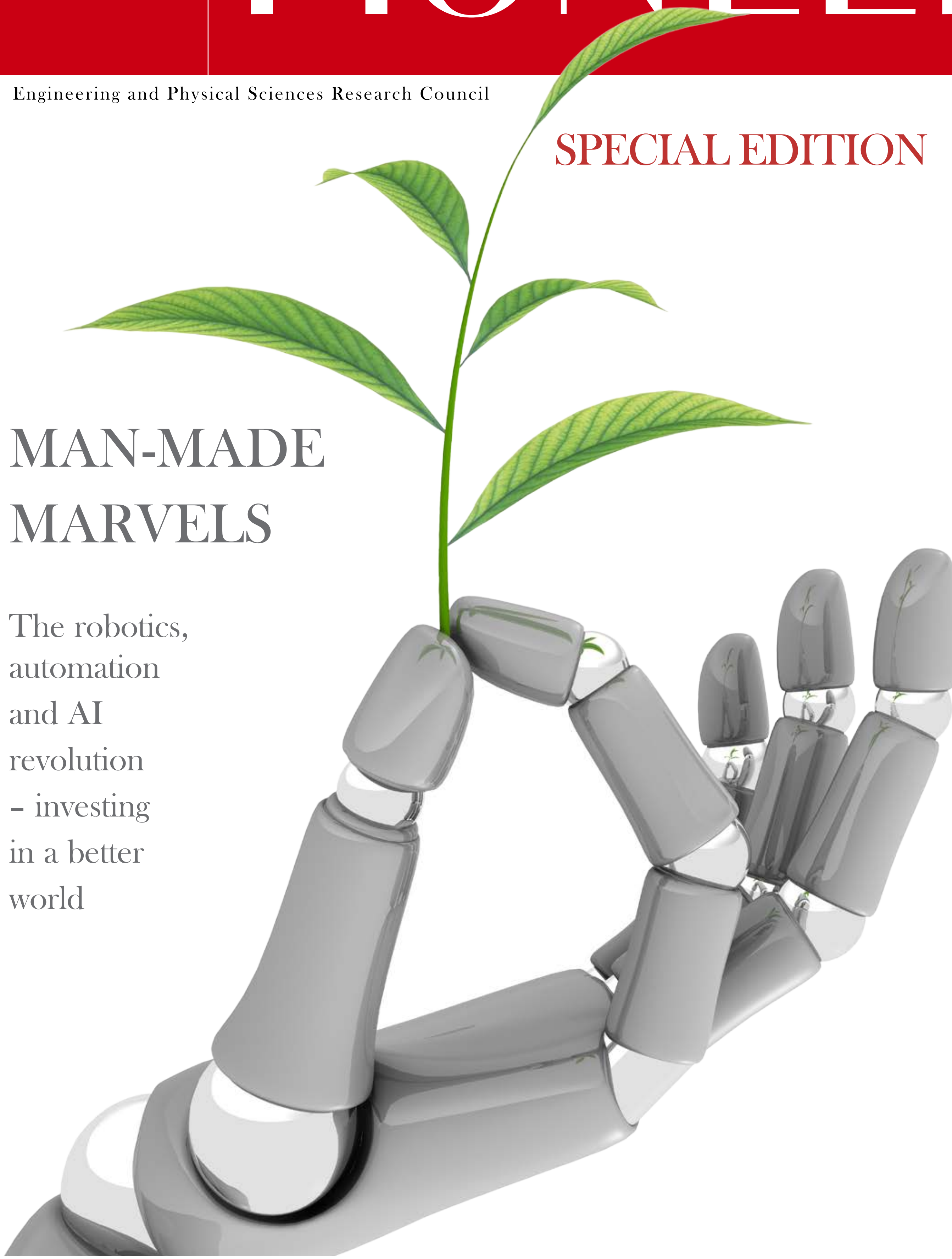

MAN-MADE MARVELS

The robotics, automation and AI revolution – investing in a better world

The car that drives itself • Surgical robotics • Helping children with autism • Robot ethics • Drones for disaster zones

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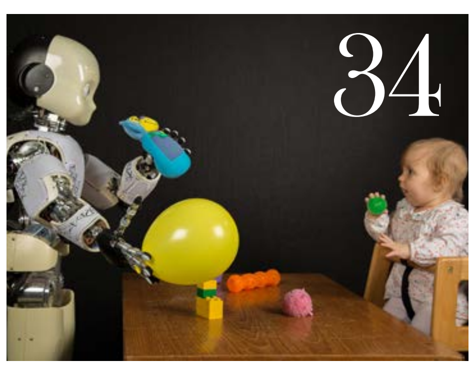

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Spirit of Leonardo

EPSRC Chief Executive, **Professor Philip Nelson**, describes EPSRC's role in supporting robotics, automation and AI research and training

In 1495 or thereabouts, among the many futuristic technologies he devised, Leonardo da Vinci drew the blueprint for a humanoid robotic knight. Packed with springs, gears and pulleys, this metal warrior could sit up, stand, raise its arms and even walk.

Fast forward to the present day and Leonardo's robot still bears comparison to the automatons being designed by major international corporations, and, of course, to the robots we see in science fiction movies.

One thing that Leonardo could not have predicted is the emergence of 'autonomous' systems and Artificial Intelligence (AI). These exciting areas of science and engineering are rapidly intertwining with robotics as we enter a new technological era. Together with digital technologies and the Internet of Things, they are at the vanguard of a fourth industrial revolution that is destined to affect everyone on the planet.

Contrary to what we see in most sci-fi films, the evidence shows we are not on the verge of robo-Armageddon. Terminator-style robots are not about to take over the world; the "more human than human" androids of *Blade Runner* will not be replacing people of flesh and blood and soul. But the technologies they embody – the intelligent systems that will safely guide our cars and aircraft and tractors, the autonomous machines capable of working in terrain inhospitable to humans, and the smart devices that will enable the elderly and infirmed to keep active – are with us now, at various stages of technological readiness.

The numbers are impressive. It is estimated that by 2025 advanced robotic and autonomous systems could have a worldwide economic impact of US$1.9 trillion to US$6.4 trillion annually, with an emerging market value of €15.5 billion. And for good reason. We already know these new technologies will be fundamental to healthcare; transport; manufacturing; agriculture; disaster response and space exploration; but the potential for human benefit seems limitless.

> "The potential for human benefit seems limitless"

For several decades, EPSRC has been at the forefront of supporting the UK's research, training and innovation in robotics, automation and artificial intelligence systems, and has been instrumental in fostering interdisciplinary partnerships between academics, industry, government and other parties.

Throughout the world, however, from the United States to South Korea, China to Japan, governments are investing billions of dollars into these new technologies. We are punching above our weight against this global competition, but we cannot afford to slow the momentum.

This special edition of *Pioneer* turns the spotlight on some of the research and innovation supported by EPSRC and its partners, and provides thought-provoking discussion on the current state of the art for artificial intelligence, autonomy and robotics. It also sets out the case for further government investment in these crucial enabling technologies while opening up a window to the future for these innovations, and for mankind.

In the zone

An EPSRC-supported research team at the University of Bristol have developed an unmanned aerial drone in response to the challenge met by helicopter pilots who risked radiation exposure as they mapped the disaster area in the wake of the Fukushima Daiichi nuclear disaster in 2011.

Oliver Payton, James MacFarlane and John Fadoulis, from the university's Interface Analysis Centre, developed the remote controlled Advanced Airborne Radiation Monitoring (AARM) system, with funding from EPSRC and Sellafield ltd.

Tom Scott, project lead and Director of the Interface Analysis Centre in the university's School of Physics, says: "By using lightweight and low-cost unmanned aerial vehicles, we can immediately and remotely determine the spread and intensity of radiation following any such event.

"The systems used by the drone have sufficient in-built intelligence for deployment following an incident and are effectively disposable if they become contaminated."

The drone uses laser distancing to enable safe flight in narrow spaces. It can map the 3D environment with millimetre precision and also capture high resolution images. The team are also developing thermal imaging, gas and acoustic sensors for the drone.

The on-board microcomputer integrates multiple sensor streams to provide radiation mapping with excellent spatial resolution and sensitivity.

The software is controlled from a laptop, and attachments can be plugged in according to what's needed. The rotor arms fold back so that the system can be fitted into a standard travel case, making it easy to take on a plane and rapidly deploy.

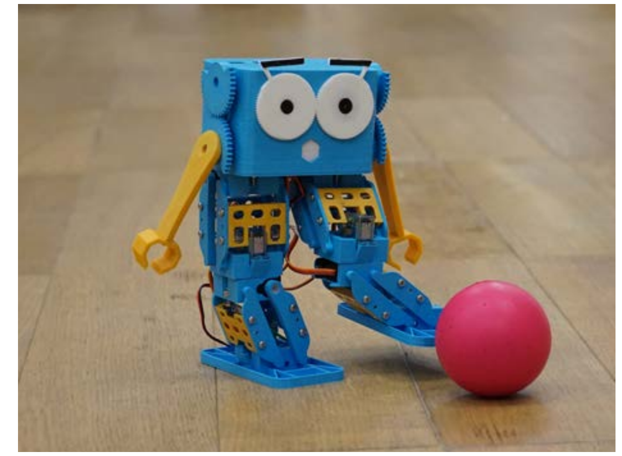
The drone has been used to map radiation surrounding the Fukushima Daiichi site to help the clean-up before people can return to their homes.

The AARM team have also provided Sellafield's first ever drone survey of any type, demonstrating the team's radiation mapping technology combined with aerial photography.

James Moore, who leads on UAV technologies at Sellafield, says: "This system, to the best of our knowledge, represents the current state of the art for radiation-mapping UAS systems."

In 2014, the Royal Academy of Engineering awarded James MacFarlane and Oliver Payton the ERA Foundation Entrepreneurs Award. The prize is helping them develop the drone commercially for use in disasters, or for routine radiation monitoring at nuclear sites or in mining operations. Spin-out company Imitec was set up to take this forward.

Earlier this year, the AARM team reached the semi-finals of the international Drones for Good competition, which received over 1,000 entries worldwide.



Mini marvel

Introducing Marty, a programmable, low-cost walking robot for children, robot 'developers', and educators.

Marty was developed by Dr Sandy Enoch as a side project during his doctorate at the EPSRC Centre for Doctoral Training in Computational Nanoscience at the University of Edinburgh under the supervision of Professor Sethu Vijayakumar and Michael Herrmann.

Sandy's work with Marty spawned a spin-out company, Robotical, and a range of functional prototypes. Robotical has already generated over £60,000 in crowd-sourced funding and has started to take orders.

Customisable with 3D-printed parts, Marty is designed to make learning about programming, electronics, and mechanical engineering a fun and engaging process. He is also completely upgradeable, and compatible with single board computers like the Raspberry Pi.

Out-of-the-box Marty can be controlled remotely over WiFi, but he can also be programmed in a variety of programming languages, from basic versions such as Scratch for children and beginners to those such as Python for experienced programmers.

Marty has drawn rave reviews since launch. *The Scotsman* enthused that Marty "could radically alter how children learn about mechanics and computer programming".

Sandy says: "Trying to get a company off the ground is probably the most time-consuming thing I've done so far, but it's also been the most rewarding for me."

Kaspar cares

University of Hertfordshire researchers have developed Kaspar, a minimally expressive child-sized humanoid robot, as a therapeutic toy to help teachers and parents support children with autism.

Designed for use as a social mediator, encouraging and helping children with autism to interact and communicate with adults and other children, Kaspar has the ability to engage in a range of interactive play scenarios, such as turn-taking or shared-gaze activities, which children with autism often find difficult to understand or perform.

Previous studies in the field of artificial intelligence and robotics have shown that a robot which looks too real can be unnerving. Thus, the research team, led by Professor Kerstin Dautenhahn, worked hard to give Kaspar a human-like but very simplified and child-friendly appearance.

Kaspar's face is capable of showing a range of simplified expressions but with few of the complexities of a real human face. He has movable arms, head and eyes, which can be controlled by a teacher or parent but also can respond to the touch of a child.

Robots that can think and act without human intervention are moving from fiction to reality. The nuclear, aerospace, manufacturing and agricultural industries are starting to develop autonomous systems that can carry out tasks that are either too difficult or too dangerous for humans, while driverless cars are already with us.

Researchers from the universities of Sheffield, Liverpool and the West of England, Bristol are collaborating on a project to ensure that autonomous robots of the future will be safer.

The new research should mean robots make decisions that are ethical and follow legislation on robotics.

The EPSRC-funded project addresses concerns that might arise around these new technologies and is linking new developments to existing industrial standards and responsible innovation frameworks.

Arria NLG, a company that is commercialising artificial intelligence technology developed with EPSRC funding at the University of Aberdeen, has been valued at over £130 million.

Research leader, Professor Ehud Reiter, says: "The goal is to build 'articulate machines' which communicate with people in the same way that other people do."

The company's technology is a form of artificial intelligence developed to communicate in natural language information extracted from complex data sources. The system automatically generates written reports which would otherwise take expert analysts many hours to complete.

Cella Energy, a company formed to commercialise EPSRC-supported research into hydrogen storage materials, and Arcola Energy have combined to develop a prototype unmanned autonomous aircraft that uses a new solid-state hydrogen power system with the potential to outperform lithium-ion batteries. For scientists, because the hydrogen-fuelled drone's engine is emission free, it opens up a whole new way to observe the atmosphere. The prototype's successful maiden flight earlier this year was supported by a grant from Innovate UK.

Table-toppers

Internationally acclaimed product designer Sebastian Conran has joined forces with EPSRC-supported researchers at the University of Sheffield to bring to market their research into assistive robotics through the launch of a spin-out company, Consequential Robotics.

The company's main focus is to develop companion and assistive robotic systems that will enhance quality of life as people age; and will build on 20 years' research at the university into developing robots that behave in a life-like way and that use control systems modelled on the brain.

Sebastian Conran, who is the University of Sheffield's Designer in Residence, supported by an EPSRC Impact Acceleration Account (IAA), says: "At the heart of our approach is human-centred design – understanding the practical needs of our users as well as their emotional wants and dreams."

Prototypes currently under development include IntelliTable, an autonomous assistive over-bed table capable of moving under its own power and which can be voice-activated using a smartphone. Together with partners including the Sheffield Centre for Assistive Technology and Connected Healthcare the company is adapting the IntelliTable platform for hospital rehabilitation therapies.

Another key project is MiRo (pictured), an emotionally engaging 'pet' robot companion. MiRo is designed to make decisions, display emotions and respond to others in a truly unique and autonomous way. The character and form of the robot have been carefully considered to be friendly and approachable, but not toy-like. A developer version of the MiRo robot is currently being manufactured and will be available to robotics researchers in early 2017.

Professor Tony Prescott, Director of the Sheffield Robotics research institute, who co-founded the company with Conran and Dr Ben Mitchinson, says: "I'm convinced of the value of including design at an early stage in the development of robotic projects.

"Our emphasis is on understanding how people will use robots in their lives at home, at work, and in shared spaces. Robots will be the eyes, ears and hands of the intelligent house or the smart office, designed to work quietly, safely and unobtrusively; complementing and assisting people, not replacing them."

World's first printed aircraft

EPSRC-sponsored engineers at the University of Southampton have designed and flown what is claimed to be the world's first 'printed' aircraft, which could revolutionise the economics of aircraft design. The Sulsa unmanned air vehicle (UAV) was featured on an October 2016 edition of Channel 5's *The Gadget Show*.

The entire structure of the UAV, including wings and integral control surfaces, was 3D-printed on a nylon laser sintering machine, which fabricates plastic or metal objects, building up the item layer by layer.

No fasteners are used and all equipment is attached using 'snap fit' techniques so that the entire aircraft can be put together without tools in minutes.

The aircraft, which was built in partnership with 3D-printing specialist RD3T RPD, is also equipped with a miniature autopilot developed by Dr Matt Bennett, one of the members of the team, which is led by Professors Jim Scanlan and Andy Keane.

Professor Scanlan leads a number of pioneering EPSRC-funded projects involving unmanned and autonomous air vehicles, including low-cost drones that, once launched, can navigate autonomously using GPS.

Another project, dubbed MAVIS (Massive Atmospheric Volume Instrumentation System), is developing low cost, biodegradable micro air vehicles. The team intends to build a fleet of these aircraft which can be launched en masse from a

high altitude balloon to gather data on the atmosphere beneath as they descend. Such data is essential for building better models of our weather and climate.

As post-flight retrieval is not always possible (such as in remote areas) the aircraft have to be light, cheap, biodegradable and able to transmit the data they measure via a radio link. The team's solution has been to build a unique paper aeroplane. The electronic circuitry the aircraft needs to make measurements and send them home is printed directly onto the paper using consumer-grade products, such as an inkjet printer and ordinary photo paper.

In future the team aims to design ways in which fleets of MAVIS aircraft can work together as a swarm and can respond in an autonomous manner to changes in the environment, such as when one of the vehicles identifies a promising region in the search for an aerosol cloud.

Life saver

Dr John Day from the University of Bristol is leading a project to develop a new unmanned aerial vehicle (UAV) capable of surveying potentially mined areas and mapping the location of buried landmines and explosives.

The technology developed by Dr Day has already been successful in measuring radiation levels at nuclear sites where it would be unsafe for people to enter, and this project will extend this technology for use in humanitarian landmine detection.

The UAV will be fully customised for landmine detection and will be capable of carrying varying sensors and relaying important data in real time.

The project is funded by Find A Better Way, a landmine detection technology research charity founded by Manchester United legend Sir Bobby Charlton, in collaboration with EPSRC.

The universities of Nottingham, Oxford and Warwick, led by Nottingham's Professor Stephen Morgan, are carrying out 'blue sky' research into artificially-intelligent medical devices that will improve treatment for cancer and intensive care patients and those with chronic wounds.

The future technologies will continuously monitor critically-ill patients and administer medicines or adjust treatment automatically, using feedback from built-in sensors.

The EPSRC-supported team's aim is to provide more personalised, accurate and timely care and, ultimately, to save lives.

A tracking system based on eye-safe lasers, developed with EPSRC support at the University of Oxford, could enable aircraft, unmanned aerial vehicles and even orbiting satellites to transmit vital data to ground stations more securely, quickly and efficiently.

The proof-of-concept HYPERION system, developed through Innovate UK's HITEA programme and with Airbus Group Innovations, has a range of 1 kilometre and has been successfully tested in-flight. Work is under way to extend this range.

HYPERION could also enable airliners of the future to offload huge amounts of technical and performance data gathered by on-board sensors to ground crews during final approach to an airport, speeding maintenance procedures and cutting turn-round times.

EPSRC-supported researchers at the University of Sheffield have created an aquatic robot which could be used during underwater search and rescue operations.

The researchers developed a set of robotic modules that, similar to the way things are built with Lego, can be assembled into robots of arbitrary shape. This allows robots to be customised to meet the changing demands of their task.

Each module is a cube and has four micro pumps which allow it to move around independently in the water. This type of robot could also be used by utility companies wanting to deal with blockages or faults in pipes that are difficult and expensive to access from the surface.

PEOPLE

Seeing's believing

Researchers from the University of Bristol, co-led by doctoral student Ilse Daly, have found the eye-rolling behaviour of mantis shrimp helps them see the world around them. The work could lead to the shrimp's unusual eye movements being replicated to produce an advanced automated visual system.

Mantis shrimp are able to see the polarisation of light, and by rolling their eyes they actively improve the polarisation contrast of objects in their marine environment.

Research leader, Dr Nicholas Roberts, says: "We have known for a while that mantis shrimp see the world very differently from humans.

"They can use 12 different colour channels (humans use only three), and can see the polarisation of light. But the eye movements of mantis shrimp have always been something of a puzzle. Intuitively, a stable eye should see the world better than a mobile one, but mantis shrimp seem to have found a different way to see more clearly."

According to the researchers, the discovery has exciting implications for robotics. If the mantis shrimp's extraordinary powers of sight can be replicated, it could lead to the development of an automated visual system with a range of applications, including underwater exploration and materials analysis.

An automated visual system that can mimic the mantis shrimp eye could provide a low-power, high-performance piece of technology, with applications ranging from underwater exploration to materials analysis.

The research was funded by EPSRC, the Biotechnology and Biological Sciences Research Council (BBSRC), the US Air Force Office of Scientific Research, the European Commission and the Royal Society.

Pee power

In 2005, EPSRC funded a pilot project imaginatively titled Smart Gut for Energetically Autonomous Robot. The grant, awarded to Professor Chris Melhuish and Dr Ioannis Ieropoulos, from the Bristol Robotics Laboratory (BRL), a University of Bristol/University of West England research facility, spawned a host of follow-on projects, and has led to an exciting partnership with the charity Oxfam.

The core technology for the research was developed for Eco-bot (pictured), a robot which uses microbial fuel cells (MFCs) to power itself by digesting waste, and thus generate energy. Live microorganisms inside the fuel cell process the waste to produce electricity.

A unique aspect of the team's research is the use of urine as a waste material to power the MFCs. Every day, around 38 billion litres of urine are produced by humans and farm animals worldwide – the energy from which could potentially be harnessed by scaling up MFCs into stacks.

Another aspect of the research is the use of waste from oxygen-producing organisms such as algae within a self-sustaining system through which the bacteria use their own waste to produce energy.

The latest generation of the robot, EcoBot-III, collects its own food and water from the environment, making it potentially capable of sustaining itself in remote or hazardous environments.

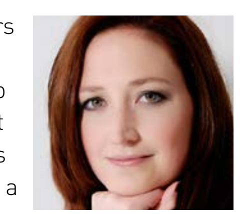
The research led to a US$100,000 grant from the Bill & Melinda Gates Foundation and the development of a prototype MFC urinal, in partnership with Oxfam and supported by EPSRC, that could light cubicles in refugee camps. The system was an instant hit at the 2015 Glastonbury Festival, unlike Kanye West.

Dr Ieropoulos says: "Not only is the technology we are developing a green and sustainable means of electricity generation, it can also improve sanitation. The work carried out under the new EPSRC grant is primarily focused at developing this technology for the developed world."

Lip service

Scientists at the University of East Anglia in Norwich, England, are working on the next stage of automated lip reading technology that could be used for deciphering speech from video surveillance footage.

The visual speech recognition technology, created by Dr Helen Bear and Professor Richard Harvey of the university's School of Computing Sciences, can be applied "any place where the audio isn't good enough to determine what people are saying," says Dr Bear (pictured).



The technology uses deep neural networks that 'learn' the way people move their lips. Researchers 'train' the system using one person's lip movements, then test it on another person's lip movements. From a database of 12 people, the technology had a success rate of 80 per cent with a single speaker.

Professor Harvey says: "Lip-reading is one of the most challenging problems in artificial intelligence, so it's great to make progress on one of the trickier aspects, which is how to train machines to recognise the appearance and shape of human lips."

EPSRC-supported researchers at Lancaster University have developed remote-controlled, submersible machines that could be used in disaster areas such as the Fukushima Daiichi nuclear power plant in Japan, scene of the 2013 tsunami which damaged three of the six reactors. The stricken facility had to be flooded with sea water to prevent further damage.

The machines will be used to assess underwater radiation and check the safety and stability of material within submerged areas of nuclear sites. This technology has the potential to be used by the oil and gas sector for assessment of naturally-occurring radioactive material in offshore fields.

The technology could also be used to speed up the removal of nuclear waste from decaying storage ponds at the Sellafield reprocessing facility in Cumbria – shortening decommissioning programmes and potentially yielding significant savings for taxpayers.

Mechanical engineers at the University of Birmingham are developing 'disassembly' processes that could lead to autonomous robots being used in the UK remanufacturing industry.

Remanufacturing is the process of returning a product to at least its original performance. Compared to manufacturing, it can use as little as 10 per cent of the energy and raw materials required, while saving more than 80 per cent in CO_2 emissions.

The EPSRC-supported team aim to gain a fundamental understanding of disassembly processes in order to develop systems that can autonomously handle variabilities in a product.

Principal Investigator, Professor Duc Pham, says: "We intend to make the robots collaborative, which means they can work with people safely and do not need to be put into cages."

EPSRC-supported scientists at Manchester Metropolitan University have developed a high-tech radar scanner which automatically detects hidden weapons on people. The device uses artificial intelligence to differentiate between common items such as keys from those that present an immediate threat to security and safety.

Navigation nous

Guidance Marine, a spin-out company which has its origins in EPSRC-supported research at the University of Oxford in the 1980s, has been identified for the second consecutive year as one of the '1,000 companies to inspire Britain' by the London Stock Exchange.

The company was formed in 1991 as a result of a long-standing EPSRC-supported collaboration with GEC. It was founded by Professor Mike Brady, then director of the highly successful Robotics Research Laboratory at Oxford.

Formerly known as Guidance Control Systems, the company is a leading global developer and supplier of positioning systems for ships, and has a reputation for the highest level of safety, reliability and ease of use.

Among a host of products, the company's LS5 'intelligent' laser scanner, introduced in 1995, was the first product launched for the autonomous vehicle market. Today, the company is a world-leading supplier of real-time vessel positioning and manoeuvring systems for critical offshore, inshore and inland marine applications.

The company is twice winner of The Queen's Award for Enterprise: International Trade, exporting nearly 90 per cent of what it manufactures from its facility in Leicester.

Flight of the Demon

In 2011, Demon, an unmanned 'autonomous' aircraft developed through EPSRC's Strategic Partnership with BAE Systems, became the first aircraft in the world to fly without the use of flaps – and into the *Guinness Book of World Records* for the first flight using no conventional control surfaces.

Headed by BAE Systems and Cranfield University, the research project brought together 10 universities to develop technologies for future unmanned air vehicles (UAVs). The all-new technology was designed by the universities and built by BAE apprentices.

The advantages of 'fluidic' flight over moving flap technology are considerable – lighter and fewer moving parts, lower maintenance, a more stealthy profile and reduced noise.

While Demon is not expected to go into production, the project has been recognised as having taken academic research to higher levels of technology readiness and closer to industrial exploitation than usually possible. Its innovations are filtering through to other aviation platforms.

The aircraft can fly without conventional elevators or ailerons, relying on air jets installed across the wing to control all in-flight movement, pitch and roll.

Demon is also able to fly by itself, but with no pilot. Because it is an experimental vehicle, it is not fully autonomous.

Demon's trial flights were the first 'flapless' flights ever to be authorised by the UK Civil Aviation Authority. The project won the Aerospace Award at *The Engineer* magazine's annual awards.

Smart arms

A team of PhD students at the EPSRC National Facility for Innovative Robotic Systems at the University of Leeds, supported by Professor Martin Levesley, have developed robotic technology to assist patients' arm recovery after strokes.

The MyPAM system helps patients improve their arm functions and rebuild their strength, by guiding their arm in a regular horizontal motion, similar to stirring a cake mix.

MyPAM paves the way for a new model of physiotherapy, keeping healthcare professionals in touch with a patient's progress with intensive remote rehabilitation programmes. The technology is designed to ease stretched community services and relieve patients of some of the daily grind of solitary exercise and attending clinics.

The team have also constructed an award-winning robotic human-like arm, called ALAN, to test the MyPAM device and carry out various manoeuvres. Led by mechanical engineering student Menelaos Kanakis, the ALAN project looks at the possibility of using robots in the rehabilitation process of post-stroke patients and for testing these devices.

The forearm and hand were created using the university's 3D printer, one of the largest multi-material printers in the world, to individually create each 'bone' in the hand which were then connected together, before being put into use on the arm.

Researchers at the universities of Leeds, King's College London and Lancaster are taking part in a project to develop ways to wirelessly 'beam' power into robots and other digital systems. The project is the first collaborative UK effort to develop systems that can simultaneously transfer information and power across wireless networks.

Wireless power transfer dates back to Nikola Tesla, who experimentally demonstrated wireless energy transfer (WET) in the late 19th century, and short-range wireless charging of mobile phones and other gadgets is about to become standard.

However, the new project will focus on the possibility of longer-range wireless charging, exploiting recent advances in electronically-steered antennae that make it feasible to power robots safely over a significant distance using a microwave beam.

A key aim of the new project is to build working prototypes of wirelessly-powered robots, which will be fabricated in the new EPSRC National Facility for Innovative Robotic Systems at Leeds.

Engineers from the University of Bristol have developed a new shape-changing metamaterial using Kirigami, which is the ancient Japanese art of cutting and folding paper to obtain 3D shapes.

Metamaterials are a class of material engineered to produce properties that don't occur naturally.

The research was developed within a PhD programme run by the university's EPSRC Centre for Doctoral Training in Advanced Composites for Innovation and Science.

In future technologies, this Kirigami metamaterial could be used in robotics, morphing structures for airframe and space applications, microwave and smart antennae.

EPSRC-supported research led by Newcastle University has resulted in technology that enables amputees to 'feel' using their prosthetic limbs.

Project leader Dr Kianoush Nazarpour says the bionic arm contains a new generation of sensors which detect pressure, enabling the user to carry out complex tasks such as picking up a glass by 'sensing' the shape and feel of the object.

CDT sets sail

EPSRC and the Natural Environment Research Council (NERC) are co-investing £2.5 million in a new Centre for Doctoral Training (CDT) in the use of smart and autonomous observation systems for the environmental sciences.

Known as NEXUSS (NEXt generation Unmanned System Science), the centre will provide specialised training in this increasingly vital area, providing the next generation of environmental scientists with the necessary skills to develop and deploy ambitious new unmanned systems. They will also create a community of highly-skilled people whose expertise will contribute both to scientific breakthroughs and to economic growth.

Innovative sensor platforms such as drones and autonomous robotic submarines play an increasingly important role in environmental science, carrying out tasks from monitoring air pollution to exploring the deep ocean. To assist their research, the students will have access to NERC's ocean-going research vessel, Discovery, with its fleet of autonomous vehicles.

These systems can cover vast areas and stay in place for long periods; they are already letting scientists gather far more data than ever before. They can also be sent to places traditionally considered too difficult or dangerous for humans to work in, potentially opening up whole new fields of inquiry.

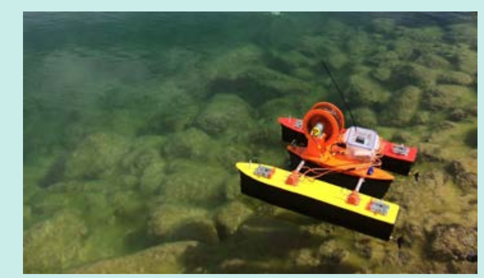
The potential applications include sectors such as renewable energy, oil and gas, deep-sea mining, farming and aquaculture. Drones could also be used to map flood zones from the air so that nearby homes and businesses can be better protected.

The consortium behind NEXUSS is led by the University of Southampton, in partnership with the British Antarctic Survey, Heriot-Watt University, the National Oceanography Centre, the Scottish Association for Marine Science and the University of East Anglia.

Sonar bot

A team of five EPSRC-supported engineering students at the University of Leeds have created a small lightweight robot carrying sonar technology that is designed to skim the surface of water courses. Its purpose is to explore the world to try to understand how global warming is affecting it.

The 'Bathybot' resembles a catamaran and can be transported worldwide due to its size and design. Its most recent mission saw it travel to Nepal to sail over 'melt pools' of glacial lakes to measure depths and collect other data which the team, from the university's School of Geography, will analyse to improve our understanding of global warming.



Robots on reins

Firefighters moving through smoke-filled buildings could save vital seconds and find it easier to identify objects and obstacles, thanks to revolutionary reins that enable robots to act like guide dogs.

The small mobile robot – equipped with tactile sensors – leads the way, with the firefighter following a metre or so behind holding a rein. The robot helps the firefighter move swiftly in 'blind' conditions, while vibrations sent back through the rein would provide data about the size, shape and even the stiffness of any object the robot finds.

This potentially life-saving application of robotics has been developed by King's College London and Sheffield Hallam University, with funding from EPSRC.

Project partners have included the charity Guide Dogs, South Yorkshire Fire & Rescue Service and Thales Ltd. Now proof of concept has been completed, the team plan to build a full working prototype for testing in real-world firefighting conditions.

EPSRC is investing £6.2 million in three projects to further knowledge and understanding of the research challenges related to autonomous systems in UK manufacturing in areas such as the aerospace, construction and automotive industries.

The University of Birmingham, Imperial College London and the University of Strathclyde, supported by companies such as Caterpillar, Kuka Robotics, Skanksa Ltd, Dyson Ltd, SPIRIT AeroSystems and Autocraft Drivetrain Solutions, will investigate areas such as automating the complex disassembly of returned products; developing the world's first aerial additive manufacturing systems for use on-site, and creating automated non-destructive evaluation systems for use in high value manufacturing.

An EPSRC-supported team from the universities of Sheffield and the West of England have designed a suite of whiskered robots inspired by rodents.

Sheffield's Professor Tony Prescott says: "For most rodents the whisker system is at least as significant as eyes are to sighted humans."

The robots are designed for use in environments which are hazardous to humans – such as natural disaster zones and fire sites – which are often cramped, full of dust and smoke, and offer limited visibility.

In 2009, the team's SCRATCHbot, which 'feels' its way using rat-like whiskers, won the Best of What's New Award from *Popular Science* magazine.

The team followed this up in 2012 with Shrewbot, inspired by the four-centimetre long Etruscan shrew, one of the world's tiniest mammals, which uses 'active touch' rather than vision to navigate its environment.

Inspired by their rodent research, the team developed a 'tactile' helmet, to provide firefighters operating in challenging conditions with vital clues about their surroundings. The helmet is fitted with ultrasound sensors that detect the distances between the helmet and nearby walls or other obstacles. These signals are transmitted to vibration pads attached to the inside of the helmet.

PEOPLE

Legobots on Mars

A system that uses Lego robots to imitate the navigation of a space rover, and which led to a popular outreach programme for schoolchildren, drew the attention of NASA which integrated it into its International Space Apps Challenge.

Dr Louise Dennis (pictured), from the University of Liverpool's Department of Computer Science, designed the system. The program she wrote allows users to remotely configure commands for the Lego Rover no matter its location – whether the machine is on the Moon, Mars or in the same room.

Dr Dennis says: "We originally developed the robot as a research tool to investigate issues around artificial intelligence, but at the same time we were interested in producing some sort of activity that could be taken into schools.

"If you are controlling a planetary rover from Earth, you have to deal with the time delay. Our system allows the children to experiment with driving the rover when there is a time delay and see how that affects behaviour."

The system was originally developed as part of a series of EPSRC-funded projects by the university's Centre for Autonomous Systems Technology, before being identified as a potential outreach activity in schools.

The NASA International Space Apps Challenge focused on space exploration and ran over 48 hours in 75 cities across the globe. It aimed to create open source solutions to a selection of problems through the combined effort of enthusiasts and experts based around the world. It included 23 NASA challenges and 25 non-NASA challenges, of which Dr Dennis' Lego Robots Challenge was one.

She says: "It's a bit circular because the program code we started out with was based on code NASA produced, so to come full circle and take it back to NASA again is very exciting."

Dr Dennis is currently a research associate working on a major EPSRC-funded reconfigurable autonomy project alongside industrial partners including BAE Systems and Network Rail.

City fixers

EPSRC-supported researchers from the University of Leeds are pioneering a national infrastructure research project which aims to create technology for self-repairing cities.

The team are developing small robots to identify problems with utility pipes, street lights and roads and fix them with minimal environmental impact and disruption to the public.

The research is part of a £21 million investment in 'Engineering Grand Challenges' research, which aims to tackle some of the major challenges facing science and engineering.

Projects include research and development of drones that can perch, like birds, on structures at height and perform repair tasks, such as repairing street lights; build drones able to autonomously inspect, diagnose, repair and prevent potholes in roads; and develop robots which will operate indefinitely within live utility pipes performing inspection, repair, metering and reporting tasks.

The team are working with Leeds City Council and the EPSRC-supported UK Collaboration for Research in Infrastructure and Cities (UKCRIC) to ensure that the robots are thoroughly tested before being trialled in a safe and responsible manner in Leeds.

The robots will undertake precision repairs and avoid the need for large construction vehicles in the heart of the city. The team are using the unique capabilities of the robotic facility at the EPSRC-supported National Facility for Innovative Robotic Systems at the University of Leeds to make new, more capable robots.

The project is a collaboration between Leeds, University College London, and the universities of Birmingham and Southampton. Research leader, Professor Phil Purnell, says: "We want to make Leeds the first city in the world to have zero disruption from street works.

"We can support infrastructure which can be entirely maintained by robots and make the disruption caused by the constant digging up of the roads in our cities a thing of the past."

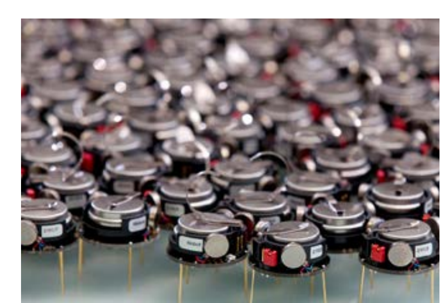
Swarmbots

Researchers from Sheffield Robotics Laboratory have applied a novel method of automatically programming and controlling a swarm of up to 600 robots to complete a specified set of tasks simultaneously.

This reduces human error and therefore many of the bugs that can occur in programming, making it more user-friendly and reliable than previous techniques. This could be particularly advantageous in areas where the safety of using robotics is a concern, for example, in driverless cars.

The researchers applied an automated programming method previously used in manufacturing to experiments using up to 600 of their 900-strong robot swarm, one of the largest in the world.

Swarm robotics studies how large groups of robots can interact with each other in simple ways to solve relatively complex tasks cooperatively. Previous research has used trial and error methods to automatically program groups of robots, which can result in unpredictable, and undesirable, behaviour. Moreover, the resulting source code is time-consuming to maintain, which makes it difficult to use in the real world.

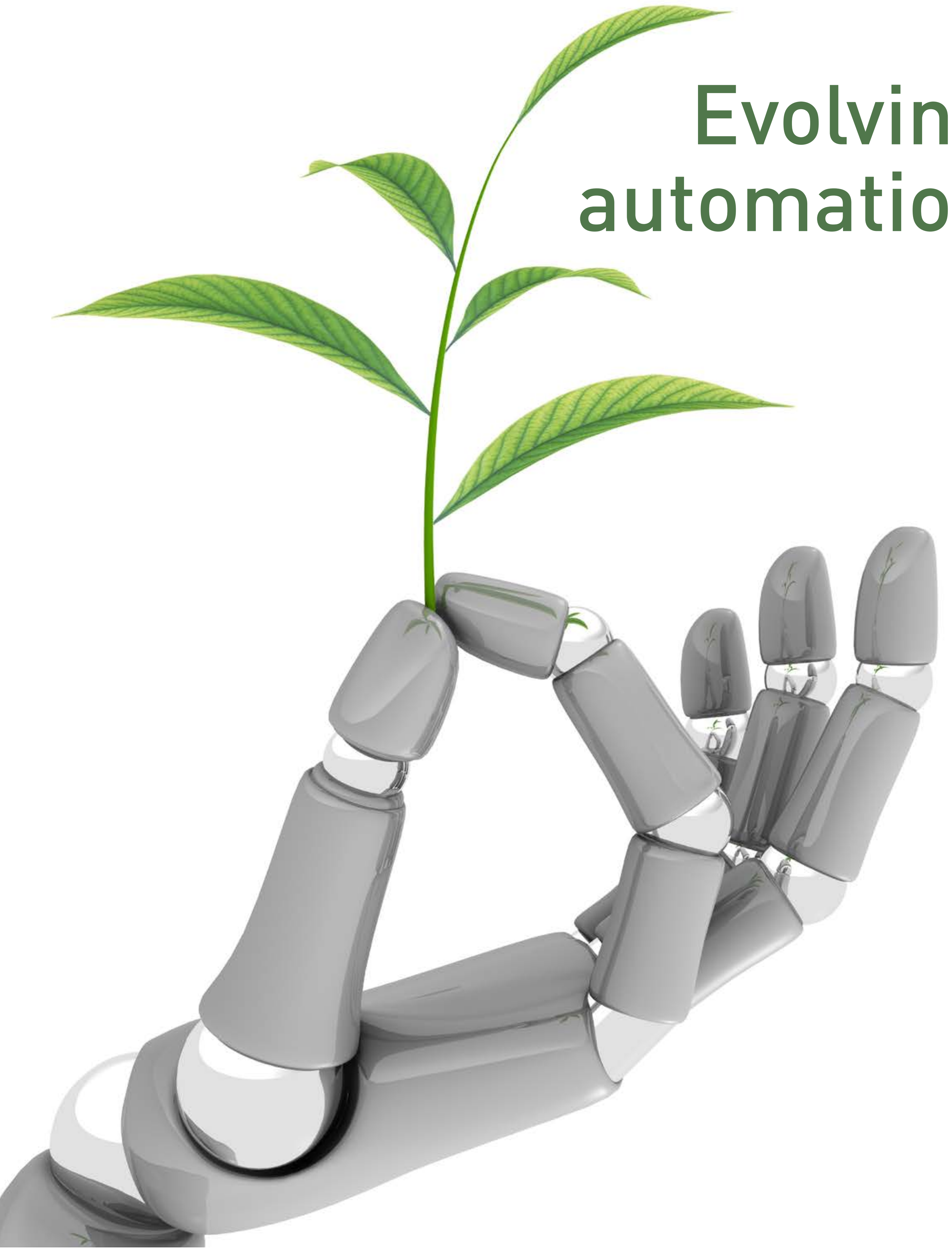


How can cars become fully independent of human direction? What is the best technology to incorporate into new vehicles and infrastructure? How will humans and vehicles interact with each other and their environment? These are just a few of the questions facing academics and industrialists working on an £11 million research programme to develop fully autonomous cars, jointly funded by EPSRC and Jaguar Land Rover.

Ten UK universities and the Transport Research Laboratory are working on the project with Jaguar Land Rover, which is leading on the research. The projects are investigating:

- The use of radar and video sensing to interpret the external environment, road conditions and other road users
- How drivers will react to new autonomous systems
- How systems can be designed to adapt to the personal characteristics of users
- How the transition between human control and automated systems can be designed to best effect
- How distributed control systems and cloud computing can be integrated with vehicles
- How data from drivers, intelligent infrastructure and automated vehicles can be used to aid interaction.

Dr Wolfgang Epple, Jaguar Land Rover's Director of Research and Technology, says: "To realise the potential for fully autonomous vehicles, we need to give drivers, pedestrians and other road users the confidence that a car driving around with little or no human input is a safe and rewarding experience. These collaborative projects will bring some of the UK's leading academics together with our autonomous driving team to address the fundamental real-world challenges that are part of our journey towards autonomous driving."



Evolving automation

Robotics, automation and artificial intelligence will change our lives forever. EPSRC Chief Executive, Professor Philip Nelson, sets out the case for further investment in research, training and innovation.

In June this year I was asked to give evidence to the House of Commons Science and Technology Committee about research into robotics, automation and artificial intelligence. It was a fascinating experience, and it was also good to see our representatives in Parliament taking this subject seriously – and as a matter of urgency.

They are right to be serious. Robotics, automation and artificial intelligence are not a thing of the future; they are very much of the here and now.

We are already seeing technologies that have traditionally been the preserve of science fiction becoming increasingly commonplace, from robotic limbs to driverless cars. Technologies that synthesise artificial intelligence, automation and robotics will work for us and beside us, assist us, and interact with us.

Sectors already benefiting from these technologies include those as diverse as healthcare, energy, transport, environment, manufacturing and aerospace, agrifood, infrastructure, security, retail and logistics, but their ultimate impact will be global, crossing cultural and technological divides.

It is estimated that by 2025 these technologies could have a worldwide economic impact of US$1.7 trillion to US$4.5 trillion annually, with an emerging market value of €15.5 billion.

The challenge for the United Kingdom is formidable. You only have to look at the investments being made in other economies, particularly in Japan and South Korea.

South Korea has an annual robotics budget of more than US$145 million and has just earmarked US$445 million for the next five years. Japan has just put US$350 million into a big programme of assistive robotics. In the United States there is a lot of private investment going into robotics, automation and artificial intelligence, particularly autonomous vehicles, from organisations such as Google and Tesla.

Despite these challenges, the United Kingdom has the opportunity to become a world-leader in developing these technologies, and EPSRC is helping to lead the way.

EPSRC currently invests £115 million in research and training grants relevant to robotics and autonomy. This includes both core robotics research and related research applied to synergies between these technologies. Our ICT portfolio also includes investments of £23.9 million into artificial intelligence and £15.7 million into human/computer interaction.

We are also investing in networks to make sure we gather together all the expertise, spearheaded by the EPSRC UK Robotics and Autonomous Systems (UK-RAS) Network, linking together outstanding specialist scientists and engineers engaged in multidisciplinary research at 16 universities.

The UK can only be successful if research goes hand in hand with innovation – particularly through academic/industry partnerships. This is something the UK Research Councils are particularly good at, and I would like to think that EPSRC leads the way in this regard. For example, over 3,100 organisations are involved

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"The UK can only be successful if research goes hand in hand with innovation – particularly through academic/industry partnerships"

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in collaborative EPSRC grants, and the total invested by business and other partners is £1.74 billion.

We are investing more and more in large-scale academic/industry partnerships. For example, in 2012 we launched the £14 million Autonomous and Intelligent Systems Partnership, involving eight companies and 19 universities. More recent investments are also proving very effective. For example, as part of our strategic partnership with Jaguar Land Rover, in 2015 we co-invested £11 million in five projects focusing on human interactions with autonomous vehicles.

A culture of enterprise

Creating a culture of enterprise is critical to growing this burgeoning sector, particularly in young people, who will be the standard-bearers and innovators in the next generation of researchers. We have thus provided further support for four EPSRC Centres for Doctoral Training located at universities within the UK-RAS Network. These centres, launched in 2013, play a vital role in equipping students with entrepreneurial skills. They have excellent role models to draw from. Seebyte, for example, which was formed in 1991 by Professor David Lane to commercialise EPSRC-supported research, is now a world leader in smart software technology for unmanned systems. A young entrepreneur already taking his ideas to market is Sandy Enoch, a former EPSRC-supported PhD student at the University of Edinburgh, founder of Robotical, which is breaking new ground in educational robots for children, hobbyists and developers.

Specialist incubators, including Edinburgh Informatics Ventures, Techcube and Codebase, the UK's largest technology incubator, are also playing their part in this pipeline of innovation.

It is also exciting to see how Research Council and stakeholder investments have reached across the research and innovation landscape, facilitating significant further funding from facilities such as the Dyson Centres at Cambridge and Imperial; the Leverhulme Centre for the Future of Intelligence; the Alan Turing Institute, and the Centre for Connected and Autonomous Vehicles. There is also great work going on at Innovate UK, which is helping accelerate research to market.

These investments have been complemented by those from the UK Government, including a £25 million injection of capital funding in various EPSRC-supported centres to develop their work.

However, it is clear there is a pressing and growing need for further investment – enabling researchers and innovators to take advantage of the momentum that has been built.

National strategy

Working with Innovate UK, the Knowledge Transfer Network, other Research Councils and stakeholders, EPSRC has built a business case and strategy for further public investment in robotics, automation and artificial intelligence, and there is now cross-sector business recognition of its importance in:

- **Growing global market share:** Independent reports suggest the UK can lead and increase its share in a rapidly expanding global market
- **Increasing UK share of global growth:** Research and development spending on robotics, automation and artificial intelligence is predicted to grow by over 17 per cent in the next four years, spurred on by industrial demand.

As part of this strategy, we have identified four key areas for investment: extreme and challenging or hazardous environments; health and social care; autonomous transport; and next-generation autonomous manufacturing.

EPSRC is playing a pivotal role in meeting these challenges through its investment in dedicated research, innovation and skills hubs such as the Bristol Robotics Lab and Edinburgh Centre for Robotics.

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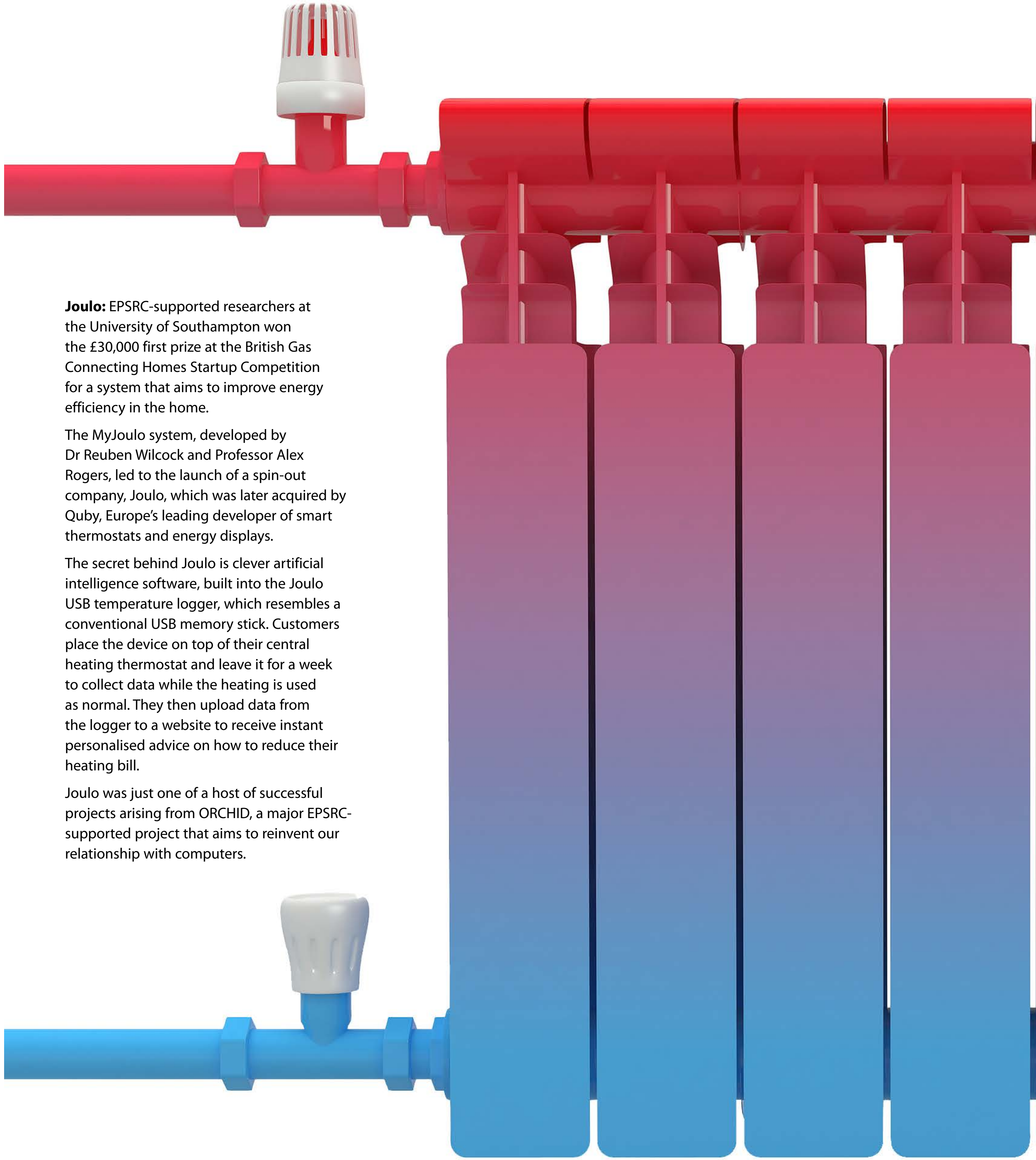
"Research and development spending on robotics, automation and artificial intelligence is predicted to grow by over 17 per cent in the next four years, spurred on by industrial demand"



Joulo: EPSRC-supported researchers at the University of Southampton won the £30,000 first prize at the British Gas Connecting Homes Startup Competition for a system that aims to improve energy efficiency in the home.

The MyJoulo system, developed by Dr Reuben Wilcock and Professor Alex Rogers, led to the launch of a spin-out company, Joulo, which was later acquired by Quby, Europe's leading developer of smart thermostats and energy displays.

The secret behind Joulo is clever artificial intelligence software, built into the Joulo USB temperature logger, which resembles a conventional USB memory stick. Customers place the device on top of their central heating thermostat and leave it for a week to collect data while the heating is used as normal. They then upload data from the logger to a website to receive instant personalised advice on how to reduce their heating bill.

Joulo was just one of a host of successful projects arising from ORCHID, a major EPSRC-supported project that aims to reinvent our relationship with computers.

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These dedicated centres are meeting industry needs by accelerating the flow of knowledge about robotics, automation and artificial intelligence technologies into the economy.

We are also opening up new business opportunities by inviting researchers to come up with solutions to specific challenges, supported by sustained Research Council, Innovate UK and stakeholder investment. For example, earlier this year with Innovate UK we invited researchers to submit proposals for a share of a jointly-funded £5 million investment pot to develop robotic innovations – helping to further build UK expertise in the sector and open up new opportunities for innovative businesses and economic growth.

EPSRC is also investing in people – expanding and enhancing UK academic capability and skills by supporting tomorrow's leaders. For example, since 2003 we have provided continuous support for the work of Professor Paul Newman, founder of the Oxford Robotics Institute. This includes a five-year Leadership Fellowship and a recent five-year Programme Grant.

This magazine reflects the huge range of cross-disciplinary research and innovation in these areas, so the foundations we are laying are strong. But we need to go further. Collectively, the Research Councils, Innovate UK and the Knowledge Transfer Network believe that the creation of a flagship-coordinated national effort would significantly enhance the national and international profile of the UK research base, providing a centre of focus for future development within the sector. For this strategy to work we must continue to develop a joined-up approach to the investments we make and in the outcomes arising from them – thus creating a sustained, long-term pipeline of research and innovation from the lab bench to the marketplace, and integrating this new thinking into technologies for a better world. We are not, however, ignoring the many complex challenges facing the development of the sector. For example, there are serious public concerns surrounding jobs and ethics.

Jobs

The impact of robotics, automation and artificial intelligence will cut across all major industries, and we are already seeing the effect they are having on manufacturing, logistics, transport, energy, healthcare, energy and retail, for example.

Advances in technology inevitably change the nature of the workforce, replacing certain types of jobs while creating new opportunities in the process – a trend that dates back to the Industrial Revolution and to the more recent rise of digital computers and the Internet boom.

Something we have learned from the Internet revolution and the rapid deployment of computers is that worries about large-scale unemployment have largely evaporated because other jobs have been created.

It is no doubt true that the synthesis of robotics, automation and artificial intelligence will supplant many activities, but experience shows that new industries and technologies rise as a consequence.

The key is to be able to upskill the workforce to deal with these changes. This requires careful and committed planning, both for the benefit of the current workforce but especially for the next generation – ensuring children embrace the sector from an early age, and nurturing an enquiring spirit that will see them create new jobs, indeed industries, in much the same way that Apple, Microsoft and, in the UK, ARM were forged from the creative minds of young people with talent, vision and ambition.

We need to be open and fully prepared for the changes in workforce structure and for a shift in the skills base. Above all, the public needs a clear and factual view of the current and future development of these technologies.

Culture

From the perspective of popular culture, which fuels public debate, robotics and AI are very much to the fore right now, with acclaimed TV series such as *Westworld* and *Humans* asking serious questions about what

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"We need to be open and fully prepared for the changes in workforce structure and for a shift in the skills base"

Drone trackers: In October 2016, a team of EPSRC-supported researchers from the University Defence Research Collaboration (UDRC), at the University of Strathclyde, won a major European award for their invention of a system that enables the tracking of UAVs. The team won the grand prize at ESNC 2016, awarded by the European Satellite Navigation Competition, the world's leading innovation platform for forward-thinking applications in its field.

The team's cutting-edge civilian UAV tracking system promises to take the use of drones to the next level. With more and more civilian and commercial UAVs, such as quadcopter drones, taking to the skies, authorities are concerned they pose a significant risk to safety and security. To enable the early detection, classification and tracking of UAVs, the Strathclyde team developed a Passive Bistatic Radar (PBR) system that aims to monitor sensitive areas such as restricted air spaces around airfields. The system could also be deployed for major public events or to support UAV use for e-commerce.

Along with their €10,000 prize, the team are set to receive an extensive package including cash, marketing support and consulting services, to accelerate their idea further towards commercialisation.

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it is to be human, and what it is to be a machine. We must embrace this debate as part of a wider national dialogue.

Through initiatives such as the UK-RAS Network's National Robotics Week, the first of which was held in June 2016, EPSRC and its partners are reaching out to the public, particularly schoolchildren, to encourage debate and stimulate action. As a community – academic and industrial – it's vital that we broaden people's understanding of the issues, both for science and society, so that we can responsibly build next-generation technologies.

Ethics and responsible innovation

It is understandable that there are public fears around robotics, automation and artificial intelligence. Building trust and embedding the core values of ethics and responsible research and innovation are the foundation of trust, and underpin good practice.

At EPSRC, we endeavour to ensure that the research we invest in is carried out within a framework of responsible innovation – and have guidelines in place for researchers to think about the societal and economic impacts of their work, especially when it comes to ethical issues.

Verification and validation

In general, technology is trusted if it brings benefits and is also safe and well-regulated. One of the reasons we trust airliners is that we know they are part of a highly regulated industry with an excellent safety record. The reason commercial aircraft are so safe is not just down to good design, it is also because there are stringent safety certification processes and, if things do go wrong, robust processes of air accident investigation.

The issue of verification and validation of autonomous systems, especially systems that 'learn' for themselves, is both extremely challenging and vital, and is the subject of many current research projects. To this end, we set up the Verification and Validation of Autonomous Systems Network, in which over 30 of the UK's leading universities have come together to stimulate, coordinate, promote and disseminate research into these technologies.

EPSRC has funded a wide range of projects looking into this subject, such as Trustworthy Robotic Assistants, led by the University of Bristol and the University of the West of England, which is developing new verification and validation techniques to ensure the safety and trustworthiness of the machines that will enhance our quality of life in the future. A related project, Being There, which has just come to an end, investigated human-human and human-robot interactions using state-of-the-art humanoid robots such as NAO.

As the field develops, there will be a clear need for standards, regulations and, perhaps, regulators. Should driverless cars, for instance, be regulated through a body similar to the Civil Aviation Authority?

Any new technology needs a framework within which to work. In my opinion it is a job for Government to help establish this framework, and ensure that the public develops trust in these systems. One caveat would be that regulation needs to be a phased process so that the practitioners and experimenters are engaged throughout, and that innovation is not stifled as a consequence.

People, not machines

The future is about people. It is not about robots; it is about human beings, and we need to make sure that the public, regulators, insurers and lawyers, for example, are involved in the way technologies develop.

Just as computers are certain to get faster and software better, technologies arising from the synergies between robotics, automation and artificial intelligence will become more and more important as we go forward.

These technologies will not stand still. Which is why, while they remain at the early stages of their development, we should all be involved in the way they evolve, helping to create a better world for everyone.

"As a community – academic and industrial – it's vital that we broaden people's understanding of the issues, both for science and society, so that we can responsibly build next-generation technologies"

Being NAO: This programmable NAO robot, developed by French robotics specialists Aldebaran, is one of the most advanced of its kind in the world, and is used by researchers in a number of fields. In the UK a team of EPSRC-supported researchers, working with a diverse range of artists, designers and game makers, collaborated on the Being There project, to investigate human-human and human-robot interactions using state-of-the-art humanoid robots such as NAO.

The project brought together five teams of researchers from the universities of Exeter, Bath, Oxford, Cambridge (formerly at Queen Mary University of London) and the Bristol Robotics Laboratory, who took NAO into public spaces around Bristol and Bath to measure human interaction with robots.


Joint account

Professor Sanja Dogramadzi, from Bristol Robotics Laboratory (BRL), has led the development of a ground-breaking robotic system that enables surgeons to put joint fractures back together using a minimally invasive approach. Supported by an underpinning EPSRC investment, it is the first robot-assisted system designed to deal with this problem.

Working alongside Professor Roger Atkins, an orthopaedic surgeon at University Hospital Bristol, and MatOrtho®, a leading UK medical device company, Professor Dogramadzi received funding from the National Institute for Health Research (NIHR) to refine the system.

Broken bones that involve joints cause considerable disability and substantial NHS costs. To work properly and avoid painful arthritis, the pieces of the joint must be put back together perfectly. Surgeons do this by making a large incision to open up the area around the joint and see the broken bits. These wounds cause pain, scarring and infection risk, and long hospital stays.

The Bristol team's surgical system combines state-of-the-art 3D imaging, pattern recognition and robotics. It begins with CT scans of healthy and fractured joints. These are 'interpreted' by a mathematical algorithm which works out the exact displacement and rotation needed for each fragment to be put back together in exactly the right place. The solution to this 3D puzzle is the starting point for the minimally invasive surgical robotic system.

Professor Dogramadzi says: "The NIHR project is driven by patient benefit that will arise from taking the latest advances in technology and using them in a real application to solve an exponentially growing number of fractures in our society.

"By working closely with surgeons we have been able to design a workable system which will function within the constraints of medicine and meet the needs of patients. The robots we are developing will enhance the work of surgeons by carrying out complex tasks suited to robots, while the surgeon, always in control, makes the decisions essential to the patient's wellbeing.

"Ultimately the system allows for earlier and less onerous surgery; reliable, perfect fragment realignment; improved patient outcomes; faster rehabilitation; reduced hospital stays; earlier return to work; fewer complications; arthritis avoidance; and significantly reduced NHS costs."

The underpinning research and creation of the prototype system was funded by EPSRC and developed in collaboration with spin-out company, Simpleware, a pioneer of 3D computer modelling software formed in 2003 to bring to market EPSRC-funded research by Professor Philippe Young at the University of Exeter.

In May 2016, Sanja Dogramadzi and her partners won the Best Medical Paper award at ICRA 2016 in Stockholm, one of the leading international forums for robotics researchers to present their work, with 2,500 delegates in attendance.

Professor Sanja Dogramadzi has been developing medical and assistive robotics research at Bristol Robotics Laboratory for the last seven years.

Her research builds upon her PhD and is focusing on the use of robotics technologies in healthcare settings. The work is multidisciplinary and involves working with clinicians, users and companies integrating several engineering and computing disciplines including robotics, mechanical engineering, control, optimisation and medical imaging.

Robotics expertise for healthcare applications is a combination of many skills developed over years working with professionals in different fields. Understanding clinical requirements and limitations is an integral part of the research expertise.

Driving ambition

Ground-breaking driverless car technology trialled in public for the first time has the potential to enable any machine that moves to operate autonomously – from combine harvesters to Mars Rovers.

The futuristic car pictured is the latest generation of self-driving vehicle developed by EPSRC-supported engineers at the Oxford Robotics Institute (ORI) – and is the first to be driven on public roads in the UK.

In successfully completing the first public trials, conducted in real time on pedestrianised streets at the heart of Milton Keynes, the team behind the LUTZ Pathfinder pod demonstrated how the vehicle, guided by software that builds 3D models of its surroundings, can navigate autonomously while avoiding unpredictable obstacles or hazards such as children running into the road. The vehicle can do this using vision or laser – or a combination of both.

The team's research led to the creation of a spin-out company, Oxbotica, which has played a pivotal role in the project, integrating the ORI's software into the vehicle, giving it the next-generation level of intelligence to safely operate in pedestrianised urban environments.

Project leader and Oxbotica co-founder Paul Newman, BP Professor of Information Engineering at the University of Oxford, has been at the forefront of research into mobile autonomy for more than a decade. He says continuous EPSRC support for his research, which dates from 2003, and includes a prestigious 2010 Leadership Fellowship to develop 'Life-Long Infrastructure Free Robot Navigation' as well as a £5 million, five-year Programme Grant, awarded in 2015, has been "vital".

"Thanks to ongoing EPSRC support I have been able to build an ecosystem of scientists, mathematicians, engineers and research assistants," says Professor Newman, who co-founded Oxbotica with his ORI colleague Ingmar Posner, Associate Professor in Information Engineering.

Posner and Newman's work led to the creation of Selenium, the crucial software at the heart of the project that enables the vehicle to satisfy questions driven by the "basic pillars of autonomy", as Newman describes them: Where am I; What's around me; and What should I do?

Rather than utilising GPS, which can be disrupted if used in tunnels, underground or underwater, for example, Selenium uses data captured by on-board cameras and Light Detection And Ranging (LiDAR) laser measurement devices to enable the car to create 3D models of its surroundings, building up knowledge of the surrounding environment.

Professor Newman says: "With the Selenium platform we can take any vehicle and make it into an autonomous vehicle – from forklifts to agricultural machinery.

"If something can be touched and moved by machines, we can make those machines autonomous – moving parcels in warehouses, cabbages in fields, rocks down mines and people along streets."

Wider potential applications include use in manufacturing, the surveying of potholes in roads, and even space exploration. Oxbotica's navigation software has been licenced for use on the European Space Agency's ExoMars project.

Key to the research has been the involvement of industrial partners – from BAE Systems, to Nissan, to Jaguar Land Rover. The team is currently challenging itself with seamlessly integrating Selenium into the latest Range Rover model.

The LUTZ Pathfinder project was backed by Innovate UK, and the Milton Keynes trials were in partnership with the Transport Systems Catapult, which is building an automated vehicle test and integration facility to enable other UK universities and SMEs to work with the Catapult on new self-driving technology.

Although the successful Milton Keynes trials brought the LUTZ project to a close, it has left a legacy that could see the first commuters travelling in self-driving cars within the next five years, with three routes planned between railway stations and specific sites in Oxfordshire, one of which is the EPSRC-supported RACE robotic remote handling facility in Culham, south Oxfordshire.

Photography Mark Mallett

Spin doctor

A team of researchers led by Dr Mirko Kovac are developing autonomous aircraft that can fly into disaster zones and print emergency shelters.

Dr Kovac's team, from Imperial College London, are working with academic partners and industrial collaborators to combine a suite of technologies that could be used in disaster relief and in a host of other situations.

Supported by an EPSRC manufacturing grant, the team are developing autonomous drones, miniaturised 3D printers and artificial 'swarm intelligence' systems which would allow the robots to build life-saving structures in places that are too dangerous or difficult for construction teams to get to.

Dr Kovac, Director of the Aerial Robotics Laboratory at Imperial, says: "Once the site has been identified where shelters would be needed, we can create the virtual model on the computer offsite, away in a safe zone."

The concept sees swarms of drones scanning and modelling the landscape and using building information modelling (BIM) systems to print structures on the spot from scratch. It builds on research at Imperial that has already led to flying drones that can extrude 3D print material in the air, as well as simulations of swarms of drones planning and making things autonomously and collaboratively.

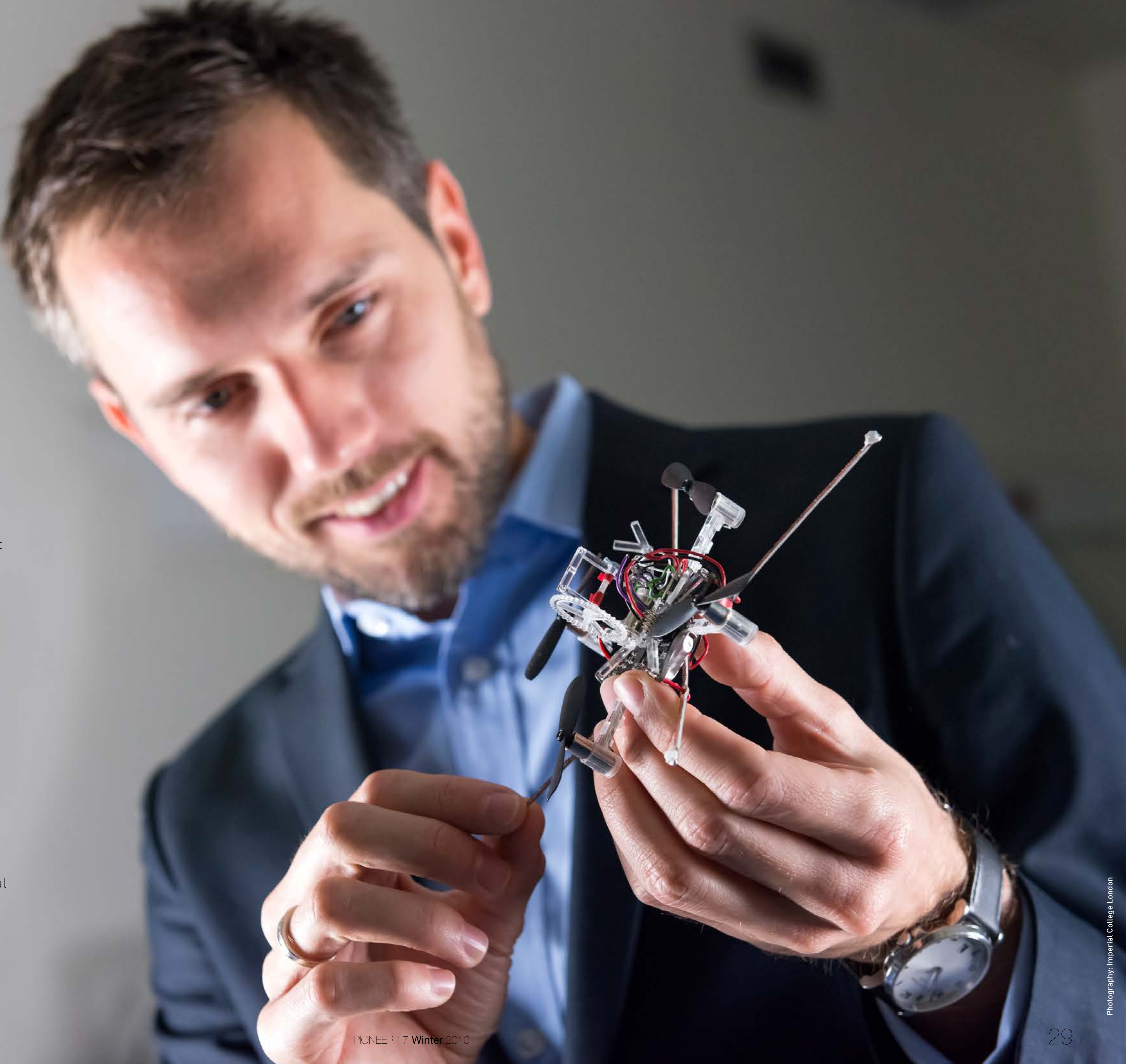
The four-year project involves researchers from Imperial College, the University of Bath and University College London. Industry partners include Dyson, engineering consultancy BuroHappold, contractor Skanska, Dutch 3D print firm Ultimaker, and the UK's BRE Trust.

Dr Kovac's team say that the world's first Aerial Additive Building Manufacturing System (Aerial ABM) could even revolutionise conventional construction by miniaturising 3D print capability, giving it autonomy, and putting it in the air.

The systems could also have wide-ranging benefits for the environment and society at large. For example, Aerial ABM can significantly reduce transportation volumes and carbon emissions – 3D printers only use the material they need to build with, with minimal wastage.

There could be health and safety advantages, too, with autonomous systems carrying out hazardous tasks previously undertaken by humans, as well as contributing to the development of smart cities, with drones sensing the environment, inspecting structures and then repairing or maintaining them.

Dr Kovac's leadership has been pivotal in the success of a related project by Imperial PhD students that uses drones to repair water and industrial pipelines. The award-winning project is the brainchild of PhD student and inventor Talib Alhinai.



Photography: Imperial College London

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Autonomous futures

Professor Sethu Vijayakumar, Director of the EPSRC-supported Edinburgh Centre for Robotics, tackles the challenges facing robotics, automation and artificial intelligence, and discusses the public's misconception of these rapidly advancing technologies. He also gazes into his crystal ball...

Within the next 10 years we are likely to see major advancements in the way robotics and autonomous systems (RAS) are used in areas such as manufacturing or packaging, leading to greater efficiency and generating cost savings.

A revolution is also under way in how these systems are used in labour-intensive industries such as mining and agriculture, where they are not just undertaking physical tasks but also interfacing with new AI-like technologies such as real-time sensing, intelligence and logistics, to make the processes safer and more efficient.

In other socially important areas that affect our day-to-day lives, such as transport or water and food security, RAS technology is increasingly applied to monitor, maintain and repair assets. There are also new novel capabilities where none existed previously such as innovative healthcare technologies, underwater mining or point-to-point drug delivery in remote geographical locations using drones.

Looking further forward, we could see the creation of micro-robotic systems designed to carry out repairs, deliver drugs or even repair cell structures within our bodies.

At the other end of the spectrum there are massive, as-yet unexplored applications such as the large-scale 3D-printing of structures for transport and housing. EPSRC continues to support blue-sky research in these areas. One day they will become a reality.

Space is another frontier that has traditionally been very receptive to RAS technology. At the Edinburgh Centre for Robotics we are collaborating with NASA and the Johnson Space Center (JSC) to develop humanoid robots capable of dexterous behaviour in complex environments for unmanned missions to Mars.

We are extremely privileged to be the only team in Europe with one of NASA's Valkyrie humanoid robots (funded partly through an EPSRC capital grant). Valkyrie's human-like shape is designed to enable it to work alongside people, or carry out high-risk tasks in place of people. Edinburgh has a preferred partnership with NASA-JSC, making it the only institute outside of a couple of universities in the US with the capacity to address these challenges.

Dedicated centres for research and training excellence in the UK, initiated and funded by EPSRC, have been crucial in addressing major challenges for RAS, and have gone a long way to improving the visibility of UK robotics research outside of the country and Europe. It has helped attract lots of talent.

This commitment to long-term investment is very important for robotics, which is a high-investment, high-return discipline requiring cutting-edge infrastructure, personnel and training. EPSRC's investments contrast with the scattergun approach we used to have, with robotics inevitably falling into the cracks between the ICT and engineering portfolios. The UK has evolved into a serious player in this domain in Europe and the trajectory is great. We have clearly put ourselves on the map.

In order to maintain this upward trajectory, there needs to be sustained investment in both people and centres. We need to encourage and provide incentives for investment from the large companies becoming interested in these centres, because it's a win-win situation. The key industrial players will develop and influence the next generation of technological leaders, while giving the centres the freedom and timescales to carry out disruptive, high risk innovations.

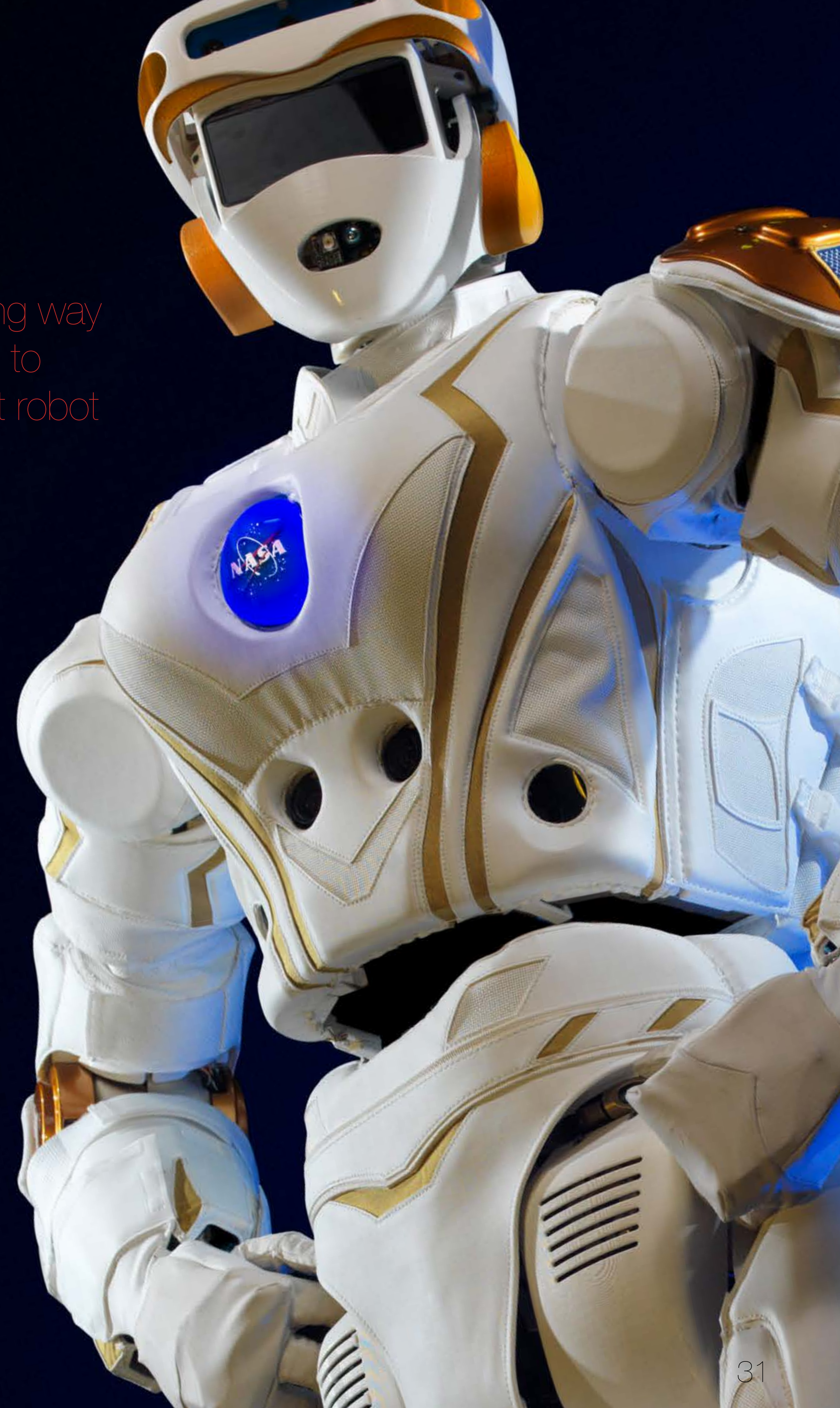
Advances in RAS and AI pose many social, ethical and moral questions. We need to ensure there is consultation not just with scientists and lawmakers but with wider society and stakeholders, the end users. We also need to manage the hype of what is possible and what is not.

Humans in general tend to overestimate the importance of new technology in the short term and underestimate it in the long term. This is very relevant to robotics because when people see an exciting new technology demonstrated they think the problem is solved, and assume they will be getting a robot butler next.

Short-term overestimation of new robotics and AI technologies can lead to concerns about robots taking over the world and such like. I know how hard it is for a bipedal robot to balance itself without falling over and breaking its ankle – we're a long way from having to worry about robot overlords. There is a gap between the vision of making robust, reactive systems and the challenges of realising it.

Nevertheless, RAS technology will significantly and positively change the way we live, work and play in the very near future. I am confident of this.

"We're a long way from having to worry about robot overlords"



One giant leap: NASA hopes to send Valkyrie humanoid robots like this one to Mars many years before astronauts are able to make the journey, for pre-deployment tasks and to maintain assets on the Red Planet. Valkyrie's human-like shape is designed to enable it to work alongside people, or carry out high-risk tasks in place of people.

People power

ORCHID, a major academic industry research collaboration, funded by EPSRC and partners, has led to world-leading science and real-world applications in areas such as disaster response, citizen science and smart energy systems. Its ultimate aim? To reinvent our relationship with computers.

As the 21st century unfolds, instead of issuing instructions to passive machines, we will increasingly work in partnership with 'agents' – highly interconnected computational components able to act autonomously and intelligently.

Funded by EPSRC and partners, the five-year ORCHID project brought together researchers at the universities of Oxford, Southampton and Nottingham and major industrial partners including BAE Systems, Secure Meters UK Ltd, and the charity Rescue Global.

Professor Nick Jennings, ORCHID project leader, says: "Human-agent collectives (HACs) are required to make sense of the volume, variety and pace of data that is available today from myriad sources and devices.

"By flexibly combining the best of human ingenuity and problem-solving with machine intelligence we can hope to build the complex socio-technical systems required by tomorrow's applications."

A case in point is the project's development and testing of new systems to support the management and coordination of disaster response. Faced with disaster situations such as earthquake, forest fire or flooding, rescue services have to make critical decisions, often drawing on uncertain information and within a rapidly changing context. Where are the casualties? Where are the resources? How is the situation changing? ORCHID researchers developed systems that can collate, interrogate and manage information drawn from a variety of sources including social media, CCTV and crowdsourcing.

Among numerous success stories, a team of ORCHID researchers from the University of Southampton designed a new tool to help monitor national radiation levels in the aftermath of the 2011 nuclear accident at Fukushima-Daiichi in Japan. The technology they created intelligently harnessed the power of crowdsourced data from private individuals who deployed 577 Geiger counters across the country to help the public track the spread of airborne radioactive particles. To identify accurate information from so many sources, the platform combines reports from thousands of sensors and uses machine learning algorithms to correct for inconsistencies and weed out defective sensors.

ORCHID's crowdsourcing/citizen science-based technology was subsequently applied to a real-world disaster response situation with Rescue Global immediately following the earthquake in Nepal in 2015.

In the field of smart energy, ORCHID research led to Joulo, a spin-out company whose technology provides 'clever' insight into heating systems, allowing customers to save money on their energy bills and make their homes more comfortable. Joulo was tipped as the UK's brightest home tech start-up when it won first place at the 2013 British Gas connecting homes competition.

A key element of ORCHID was the swift transfer out of the lab and into the marketplace. BAE Systems' Knowledge Transfer Officer, Dr David Nicholson, says: "You can do the research in the universities and build demonstration systems, but getting research into real products and systems is difficult. In ORCHID we've gone a long way to close that technology readiness gap."

Although ORCHID has now finished, its research agenda and research network continue to flourish. ORCHID directly trained and employed 50 researchers and doctoral students and has spawned 30 follow-on projects worth £15 million stretching beyond the initial universities and partners. The project has also established a new multidisciplinary research community and deployed real-world applications of human-agent collectives that will endure and be further developed.

In September 2016, in the latest from a long list of international prizes and accolades, the ORCHID project won the top prize in the Data and Connectivity category at *The Engineer* magazine's Collaborate to Innovate Awards.

ORCHID highlights

The Cicada app: A smart phone app to help locate the New Forest cicada – this has been downloaded by over 5,000 members of the public.

CollabMap: A crowdsourcing system to construct emergency maps in the aftermath of major disasters.

Apocalypse of MOP: An on-line game developed to explore understandings of provenance.

The CrowdScanner system: Developed for, and won, the US State Department's TAG challenge for social mobilisation and rapid information gathering.

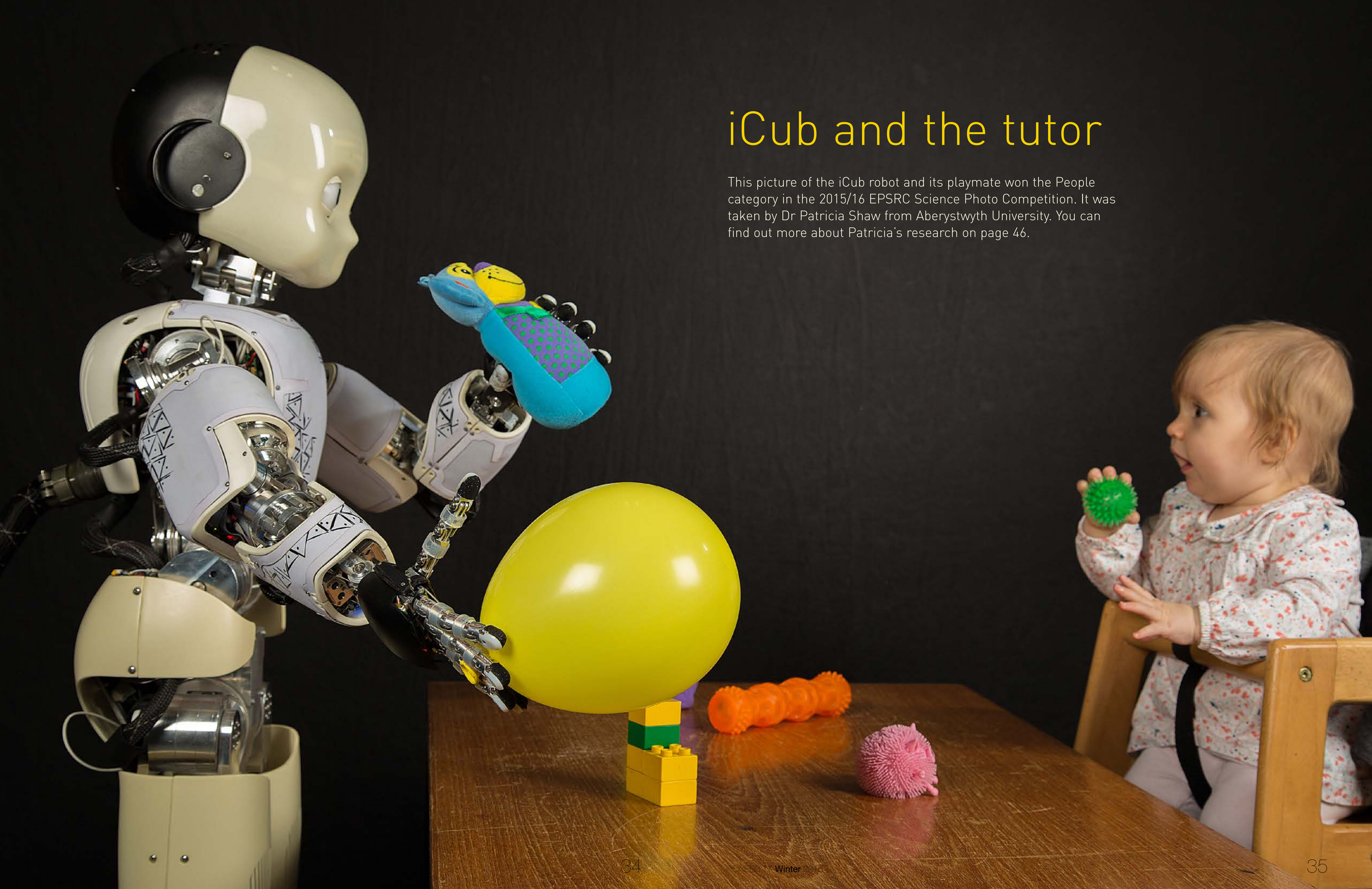
Squadguru (squadguru.com): An automated fantasy football manager that has outperformed 2.5 million players in the online Fantasy Premier League.

The OutrunCancer platform: Launched to evaluate networked incentive schemes in collaboration with Cancer Research UK.

GalaxyZoo: ORCHID technology is used in a large-scale project of galaxy research; classifying millions of galaxies.

SharedTask App: An award-winning crowdsourcing app that aims to classify tweets. Developed in collaboration with Microsoft Research.

Hire and Fire for TREC: A crowdsourcing app that helps recruiters to detect trustworthy and capable workers.



iCub and the tutor

This picture of the iCub robot and its playmate won the People category in the 2015/16 EPSRC Science Photo Competition. It was taken by Dr Patricia Shaw from Aberystwyth University. You can find out more about Patricia's research on page 46.

I think?

Professor Tony Prescott, Director of the Sheffield Robotics research institute, discusses the ethics of robotics, automation and artificial intelligence.

The fourth industrial revolution – the era of autonomous machines – is upon us and we urgently need to reflect on how this is changing UK society and how to ensure there are positive impacts for all.

People already worry about the impacts of automation on jobs, the use of robots as weapons, invasion of privacy, and possible loss of human autonomy (AI systems making decisions for us). Some changes are gradual, coming with little fanfare, but we need to be attentive to their cumulative impacts on our freedoms and lifestyles.

For example, while robotic and AI technologies will create jobs in the near-term, it is likely they will eventually take on many roles currently performed by people, possibly leading to job losses, or reduced working hours. We need to start thinking about this now.

A key benefit could be a rise in standards of living. People will do less dreary, repetitive or unfulfilling work with the possibility of replacing this with activities focused on family, social life, education, arts, and self-realisation. Hurray, we might think!

Nevertheless, evidence suggests that automation might actually lead to greater wealth inequality, leaving many people considering a less secure future.

To meet this challenge, governments may need to make substantive changes to taxation and social security, or consider more root-and-branch approaches such as a switch to universal income. Taxing robots has even been mooted, possibly not as crazy as it sounds.

In 10 years we are likely to see increased use of robotics in our public and personal spaces. For instance, in health and social care, which is the area of focus of our new spin-out company, Consequential Robotics, there are potentially many benefits for an ageing UK population.

In 15 years there will be a 50 per cent increase in those over 65 and the proportion of older people in our society will continue to grow. Robotic systems could mitigate some of the most significant effects of this shift, including labour shortages as skilled older workers retire, and health and social care services' capacity to support an ageing population. New, safe, human-friendly robots could help extend the active, independent lives of older citizens at home and at work.

At the same time, there are concerns about replacing human care with machine care and these need consideration. For me, one lesson is that we must work to make robots complementary to human carers, and perhaps consider legislation that protects a basic right to some direct human contact.

In the far future, there is the question of whether robots and AIs could achieve a level of general intelligence and autonomy where we would need to see them as other beings, potentially with rights. People may form personal relationships with such AIs.

Ultimately, there is the risk of the so-called 'technological singularity' – the moment at which humanity is surpassed by its own super-intelligent creations. While these outcomes may seem like science fiction, they are, at least, theoretically possible and are the focus of many TV shows and movies that make them seem believable. Unsurprisingly, this unsettles people.

It is right that centres such as the University of Oxford's Future of Humanity Institute are starting to consider these possible long-term impacts. I believe that the wider research community should start giving them some thought.

Climate change shows us that human technologies can have potentially irreversible world-changing effects. It is not over-dramatising to say that long-term impacts of robotics and AI technologies could be as significant.

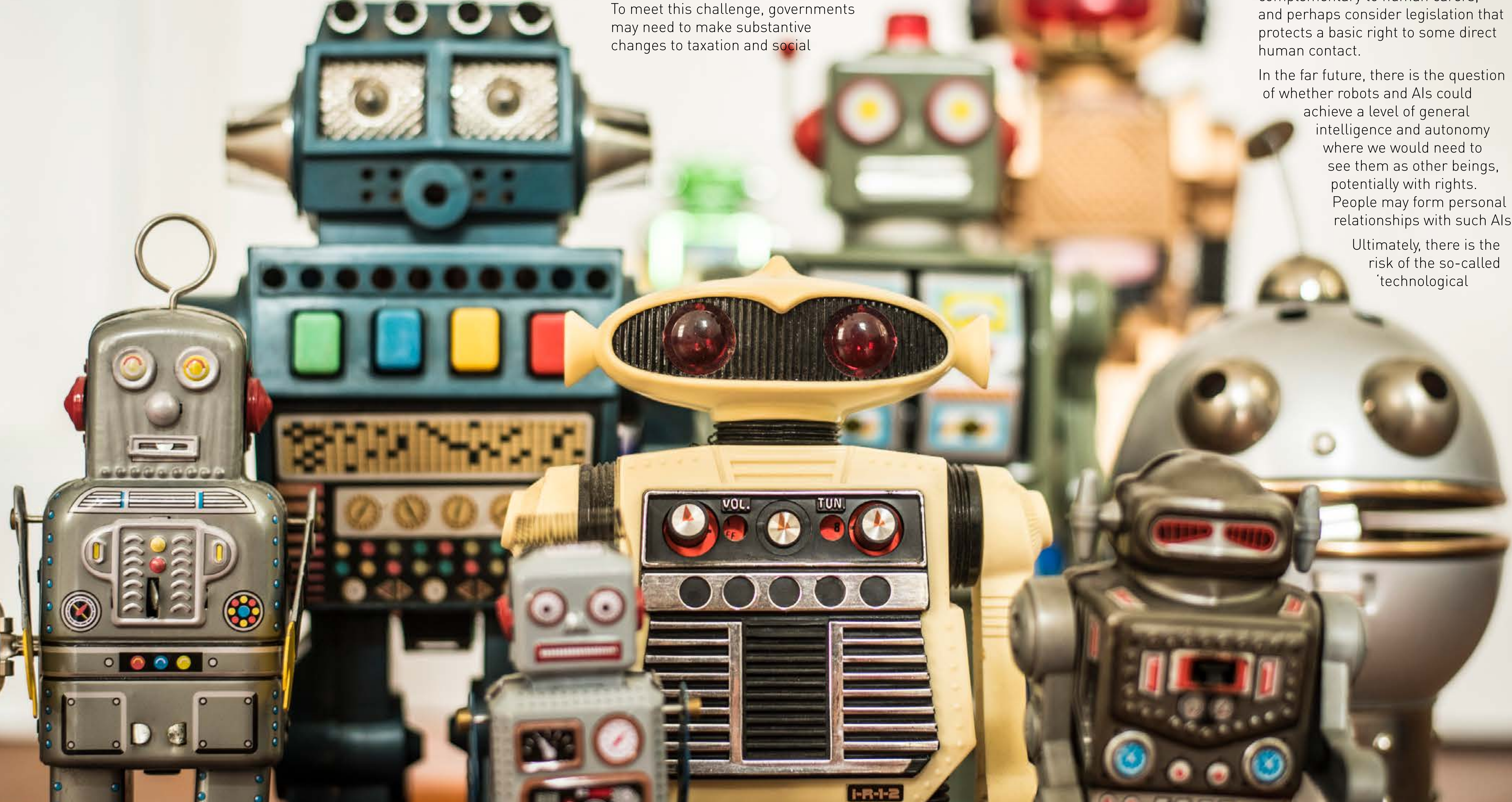
To better understand and address public concerns we will need improved science communication, and, to assure people that the research and development work we are doing is for their general good, we may also need increased governance of research and innovation in these fields.

The EPSRC framework for responsible innovation AREA (Anticipate, Reflect, Engage, and Act) is a useful starting point. At Sheffield Robotics Institute we are building this approach into the way we develop new projects, how we conduct our day-to-day research and interact with people across our city and region.

However, research in robotics and AI is global, conducted by many different types of organisation – both traditional bodies such as universities and corporations and newer and more informal players such as online and open-source 'maker' communities.

Governance and regulation will need to be international if it is to be effective and not simply promote competitive advantages for less regulated countries. It will also need to be smart and persuasive if it is going to command the attention of all possible players. I believe that the UK can and should provide global leadership in meeting this very significant challenge.

@tonyjprescott



Flight of the navigator

A tiny pilotless aircraft, built by EPSRC-supported researchers at the University of Southampton, has been deployed by the Royal Navy's ice patrol ship HMS Protector to assist with navigating through the Antarctic.

The 3D-printed aircraft, along with a quadcopter, scouted the way for the survey ship so she could find her way through the thick ice of frozen seas. It's the first time the Royal Navy has used unmanned aerial vehicles in this part of the world, and provided the icebreaker with real-time high-quality information courtesy of a detailed picture of the surrounding environment from a perspective that is only available from the air.

The laser-sintered aircraft, the world's first 'printed' aeroplane, is controlled from a laptop on board the ship, cruises at nearly 60mph and is all but noiseless thanks to its tiny engine. Its low cost means it is cheaper than one hour's flying time by a Fleet Air Arm helicopter.

Captain Rory Bryan, Protector's Commanding Officer, says: "This is an important first step in establishing the utility of unmanned aerial vehicles in this region. It has demonstrated to me that this is a capability that I can use to great effect."

Young master: Dr Kedar Pandya and Professor Guang-Zhong Yang, from Imperial College London, chair of the UK-RAS Network, with Daniel Macholl, winner of the School Robot Challenge during UK Robotics Week. The challenge is a competition for schoolchildren and students that links biology, robotics and digital skills and involves designing your own virtual robot bug and teaching it to move.

Blueprint for the future

In recent years, EPSRC has formed ever-closer bonds with partners such as Innovate UK to develop a united strategy for research, training and innovation in technologies that synthesise robotics, automation and artificial intelligence. EPSRC Associate Director, Dr Kedar Pandya and Professor David Lane, CBE, FRng, FRSE of Heriot-Watt University, look back on the formation of the strategy – and look forward to its adoption and implementation.

How will our lives be transformed in the 21st century? No-one knows for sure. However, change is all around us – from the technologies we use in our homes to the way we work, travel and play. While we cannot predict the future, we can prepare for it. We know from history that successful economies are those that invest in long-term science, technology and innovation.

Published in 2013, the now much-cited McKinsey report estimates an impact of robotics and autonomous systems on global markets of US$4.5 trillion by 2025. To put that into context, the UK economy currently has a nominal GDP of US$2.65 trillion. In May of this year, the *Financial Times* reported a doubling of global investment in robotics in the last year alone. Whereas the ICT revolution has affected everything that uses data, the revolution arising from the synergies between robotics, automation and artificial intelligence are predicted to affect everything that moves, making us more productive and safer.

For the last three years, we have worked closely together, with many colleagues and partners, to build a case for how UK investment in robotics, automation and artificial intelligence can make a long-term contribution to our economy and quality of life.

The impacts arising from this investment will happen in all sectors and all around us. It will help develop the next generation of autonomous vehicles on land, sea and air to enable better leisure travel, faster recovery during disasters and more efficient service provision. It will allow safer, more cost effective and convenient inspection and repair of critical and resilient infrastructures, such as energy and oil and gas facilities on which the UK depends, as well as help maintain the nation's historic buildings for our descendants. As populations age in the UK and around the developed world, we will increasingly look to new kinds of robotic systems to assist us in the home and across the urban environment.

Following a year's worth of consultation, debate and validation with academia, industry and public bodies, in 2014 a Special Interest Group set up under the leadership of Professor David Lane published the UK's first ever national strategy to develop our robotics and autonomous systems innovation pipeline for

jobs and growth. This provided a framework to focus the activities of all stakeholders to work coherently and develop innovation and new businesses across sectors from new technologies in the research base. Either side of that date, investments by EPSRC and other funders have helped to build UK capabilities.

In the early years, we focused our investments on underpinning capital infrastructure and collaborative research across sectors. In more recent years, key postgraduate training centres (Centres for Doctoral Training) and major programmes of research and innovation have really started to put the UK on the global map.

EPSRC and Innovate UK are working very closely with other research councils and stakeholders to show how a future integrated programme of research and translation would build on such investments. By really starting to build the innovation pipeline for robotics, automation and artificial intelligence from this promising start we can enable the UK to achieve its potential and competitive advantage.

Another first was the UK Robotics Week, set up under the auspices of the EPSRC UK Robotics and Autonomous Systems Network (UK-RAS Network), which we held in July of 2016, enthusing academics, business leaders and most importantly schoolchildren to get involved in debates, and to discuss the technological, commercial, legal, ethical and social aspects of robotics, as well as to shine a spotlight on the UK's technology leadership in RAS through challenges and demonstrators.

We were delighted by the coverage this received and there are already plans for the event to be even bigger and better next year.

As we look to the future, we have a real sense of being at an inflexion point – a distinct change in momentum. Technologies are converging at an ever-increasing rate, society is evolving at an ever-rapid pace and we know that international competitors are making major investments right now.

Early adoption is key, and here in the UK we have all the raw ingredients to be successful – one of the best research bases on the planet, an innovative business environment and a government strongly committed to a forward-looking industrial strategy. Significant government investment in robotics, automation and artificial intelligence will help the UK stay competitive, productive and ahead in a changing world. The future is now.

The EPSRC UK-RAS Network

The EPSRC UK Robotics and Autonomous Systems Network (UK-RAS Network) was established in March 2015 with the mission to provide academic leadership in Robotics and Autonomous Systems (RAS), expand collaboration with industry and integrate and coordinate activities at eight EPSRC-funded RAS capital facilities, four Centres for Doctoral Training (CDTs) and partner universities across the UK.

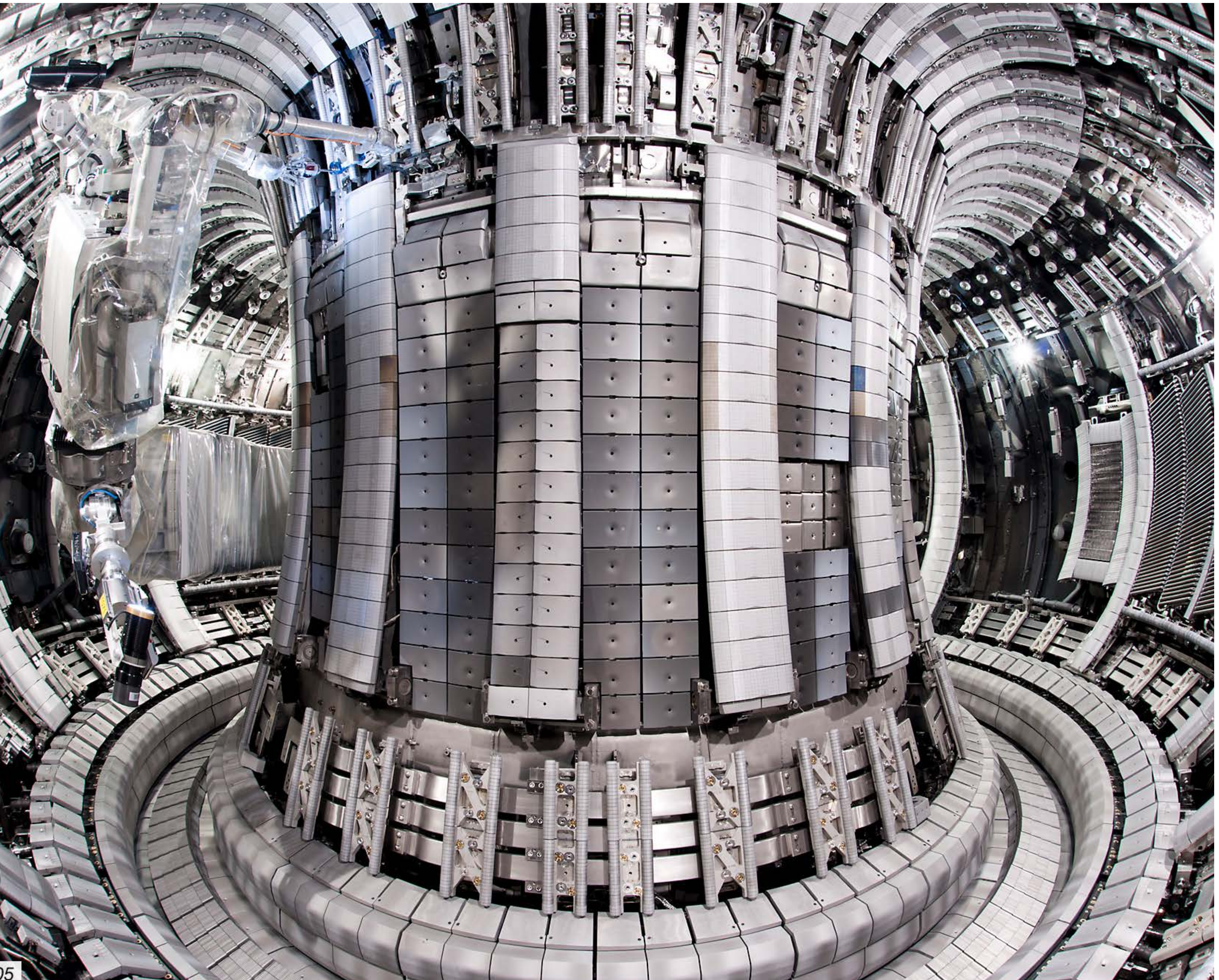
The Network, which is chaired by Professor Guang-Zhong Yang, from the Hamlyn Centre, Imperial College London, is expanding to include broader stakeholders including key national laboratories in the UK and leading international collaborators in both academia and industry. The UK-RAS Network has already received strong support from major industrial partners, the Science Museum and the UK's major professional engineering bodies including the Royal Academy of Engineering, the Institute of Engineering and Technology, and the Institute of Mechanical Engineers.

The recent capital investment from the UK government through EPSRC has resulted in the creation of the eight RAS facilities and four CDTs covering key areas of transport, healthcare, manufacturing, and unmanned systems to ensure that the UK maintains its leading engineering and research capacity in RAS.

www.ukras.org

Hands-on research: Students at the EPSRC Centre for Doctoral Training Future Autonomous and Robotic Systems at the University of Bristol.

Hotter than the sun



Mascot

Servicing and maintaining the JET nuclear fusion reactor at Culham (above), which reaches temperatures 10 times hotter than the sun, required the development of a remote handling system called Mascot (above left) which can adapt to the changing configurations and conditions of the machine.

It was not possible to use a pre-programmed or robotic type of maintenance system for JET. Instead, the system makes use of special manipulators to extend the operator's own arms into the radioactive environment. These manipulators provide the operator with a sense of touch and feel and, together with the associated CCTV system, create a sense of being inside the machine.

The units are linked by computer, not mechanically, so that the slave unit can be operated at any distance from the master. The Mascot is used to undertake a wide range of tasks including welding, cutting, bolting, handling and inspection. Many of these are performed using special tooling which in the majority of cases was designed and developed at JET.

Since its launch in 2015, the Remote Applications in Challenging Environments (RACE) centre in Oxfordshire has hit the ground running – and has been a key element in UK companies notching up over £100 million in global orders – based around its autonomous robotic remote handling technologies, developed to meet the challenges of maintaining one of the world's largest nuclear fusion reactors.

When Mary Berry takes a cake out of her oven, she wears protective gloves. After all, the oven is hot, very hot. But what if your oven is an experimental nuclear fusion reactor, which routinely heats hydrogen-based plasma up to 200 million degrees Centigrade? Such a reactor exists, in a quiet corner of south Oxfordshire, but it's not for baking cakes.

The reactor, known as the Joint European Torus (JET), is based at the UK Atomic Energy Authority's Culham Science Centre HQ, one of the world's leading laboratories investigating nuclear fusion, the process by which the sun and the stars produce heat and light.

Funding for JET comes from the 27 members of EUROfusion with the UK's component administered by EPSRC. The UKAEA plays a key role in the global fusion community with close ties to research in South Korea, Japan, China and the USA.

Fusion has the potential to provide an almost limitless clean, safe, renewable energy source for future generations. The centre is investigating how to harness this power, and one day put it on the national grid.

One way of achieving fusion is to trap a hot gas (or plasma) of fuels with a magnetic field and heat it up to temperatures 10 times hotter than the sun in a doughnut-shaped device called a 'tokamak'. JET is currently the world's largest tokamak experiment. These temperatures are not a public safety concern because the amount of fuel inside the tokamak is extremely low, weighing about as much as a postage stamp.

JET is nevertheless a nuclear facility; its central chamber is a mildly radioactive and chemically hazardous environment. Biological material does not like radiation, neither do electronics. So to keep JET maintained, scientists and engineers at Culham, drawing on 20 years' and 30,000 hours' of experience, have developed and designed remote nuclear oven gloves, or rather a suite of remotely operated robots – some up to 12 metres in length, and weighing 10 tonnes – that can work inside the JET vessel, performing tasks including welding, attachment of tiles, diagnostics, and detailed surveys.

This wealth of experience, expertise and cutting-edge technologies paved the way for a brand new government-funded £9.8 million robotics/remote handling facility at Culham called RACE (Remote Applications in Challenging Environments).

In addition to conducting research and development for the JET programme, RACE has attracted worldwide demand for its unique skills and technology, and has hit the ground running since it opened in 2016. It has already enabled industry to win £100 million in contracts from the International Thermonuclear Experimental Reactor (ITER) project, based in southern France, one of the most ambitious energy projects in the world. And its appeal goes way beyond the nuclear industry.

RACE is a key partner in and sub-contractor for the ITER project, where over 30 nations are collaborating to build the world's largest tokamak, to advance fusion science and prepare the way for the fusion power plants of tomorrow.

RACE's Director, Rob Buckingham, says: "Robotic technology will be fundamental to future nuclear power generation. ITER is essentially an industrial facility – a nuclear factory which has to be completely automated.

"Just as human beings can't survive in a radioactive environment, neither can electronics – at least for more than a few hours. We have to come up with new ways of working.

"For instance we are considering drone-sensors that can quickly fly in, collect the data we need and get out before expiring. Our goal is zero manual intervention – both during operation and for many years after shutdown."

As if this does not give the 85 engineers at RACE enough to be getting on with, remote and robotic applications outside of fusion are now being pursued in collaboration with academic and industrial partners, including with the Science and Technology Facilities Council.

RACE offers access to test facilities, robotic equipment and expertise to SMEs, multinationals, research laboratories and academia – in fact, any sector with a 'challenging environment' such as space exploration, petrochemical, construction, mining and, of course, nuclear fission and fusion.

It is estimated that robotics and autonomous systems will grow into a worldwide market worth over £60 billion in the coming years.

Rob Buckingham says: "We are also finding direct links with seemingly dissimilar subjects such as autonomous cars, which rely on advanced sensing and mapping technologies. For example, we are working with the EPSRC-supported Oxford Robotics Institute at the University of Oxford on future autonomous vehicle trials. We need mobile autonomy in fusion so are keen to work with the UK's world-leading researchers, all within the same EPSRC family."

Cling thing

EPSRC-supported researchers at the University of Leeds have used the feet of tree frogs as a model for a tiny robot designed to crawl inside patients' bodies during keyhole surgery. The tiny device is one of a growing stable of bio-inspired robots created at the School of Mechanical Engineering for which the university's EPSRC National Facility for Innovative Robotic Systems is providing unique manufacturing capability.

The robot is designed to move across the internal abdominal wall of a patient, allowing surgeons to see what they are doing on a real-time video feed.

The tree frog's feet provide a solution to the critical problem of getting the device to hold onto wet, slippery tissue when it is vertical or upside down. Although it is relatively easy to find ways of sticking to or gripping tissue, the patterns on the frog's feet offer a way to hold and release a grip without harming the patient.

Professor Anne Neville, Royal Academy of Engineering Chair in Emerging Technologies at Leeds and an EPSRC RISE Fellow, leads the research. She says: "Tree frogs have hexagonal patterned channels on their feet that when in contact with a wet surface build capillary bridges, and hence an adhesion force.

"The effect is similar to a beer glass sticking to a beer mat, but the patterns on the feet of our robot build a large number of adhesion points that allow it to move around on a very slippery surface when it is upside down.

"To work effectively, the robot has to move to all areas of the abdominal wall, turn and stop under control, and stay stable enough to take good quality images for the surgeons to work with.

"While basic capillary action works to an extent, the adhesion fails as soon as there is movement, so we have looked at the tiny mechanisms used in nature. It is only if you look at the scale of a thousandth of a millimetre that you can get enough adhesion to give the robust attachment we need."

The prototype surgical device was one of a number of the university's bio-inspired robots to feature on BBC One's *The One Show*, including an electric 'mole' designed to dig through rubble in disaster zones and a giant robo-worm that mimics the nervous system of a real nematode worm.

The use of 'structured' surfaces to manage traction/friction is exploited in the Leeds facility's latest Rollerball robot which has been designed to perform hydrocolonoscopy. Three driven rolling balls are used to propel the robot along the colon wall with the surfaces optimised for traction and minimal trauma.

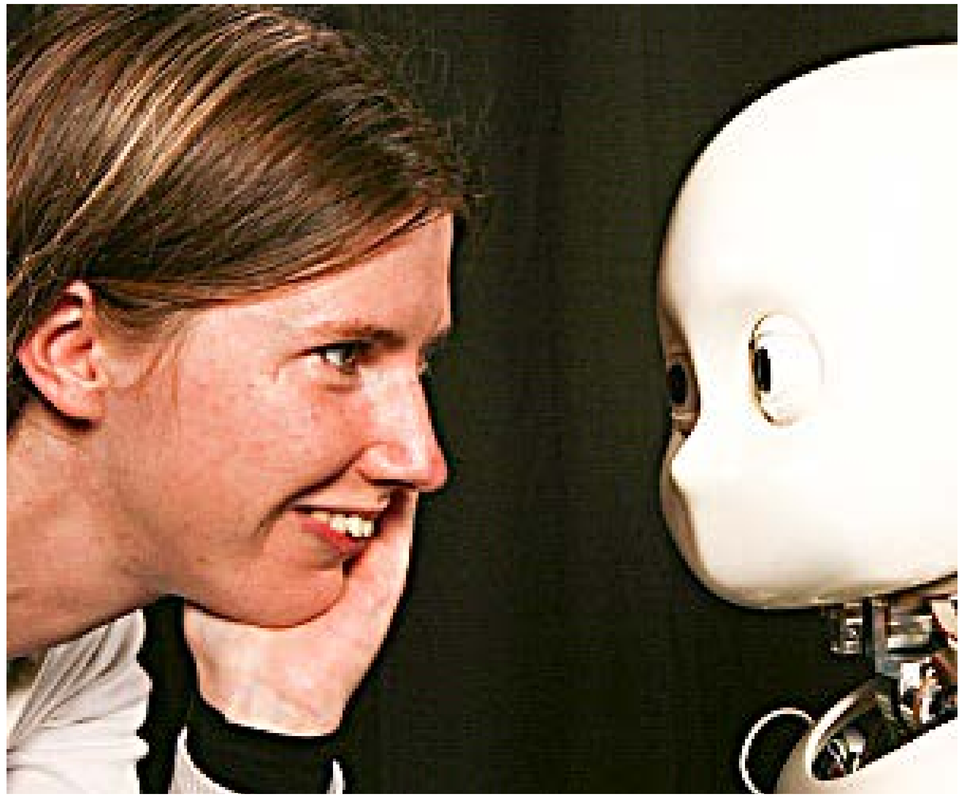
Professor Neville is a leading researcher in the fields of corrosion and tribology – the study of what happens on surfaces and at the interfaces between materials. In many engineering applications tribology has significant interactions with corrosion. In 2016 she received the prestigious Leverhulme Medal from the Royal Society for her research. The medal is awarded triennially for an outstanding researcher in the field of chemical engineering and applied chemistry.

In profile

Dr Patricia Shaw

Patricia, an EPSRC-supported researcher at Aberystwyth University, describes her passion for robots, and explains how robotics is helping her research into how humans start learning from the moment they are born.

I have been interested in computers since I was very young, trying to understand how they work and how to program them. Growing up, watching Star Trek: The Next Generation, I was fascinated by the android character Data, along with other intelligent robots in sci-fi.



When I first came across the idea of artificial intelligence, I knew this was something I wanted to learn more about, leading me to do a PhD researching Intelligent Agents. When the opportunity arose to work with a humanoid robot at Aberystwyth University, I leapt at it.

I lead a team of researchers, pushing the research forward, and am also helping to develop the next generation of engineers and scientists. Supporting the students' learning, and hopefully inspiring some of them to continue the research in the future, is highly motivating.

As robots become more commonplace, the social and psychological implications of human-robot interaction become more important. I'm lucky enough to work with an iCub robot, which is modelled on a young child.

Being humanoid in shape and child-sized, the iCub tends to elicit a friendly almost caring response from children and adults alike. This is used a lot by researchers studying how members of the public can teach the robot to perform a task. This involves a lot of crossover between computer science and psychology. I entered a picture I took of the iCub in the 2015/16 EPSRC Science Photo Competition, and was delighted when it won first prize in the People category.

I work with some really amazing people doing some great research in a wide variety of topics – from space robotics and image processing to computational biology and knowledge-based reasoning. They encourage me to keep pushing forward and doing the best I can.

The research we are doing aims to understand how humans learn starting from birth, and apply it to a robotic platform. This is really exciting because not only do we get to understand more about how our children develop, we get to use this knowledge to help the robot learn.

By helping the robot to learn about how to move and interact with its environment, it is more likely to be able to deal with unexpected situations than if it were simply told what to do. We also aim to help psychologists better understand how and why certain behaviours develop in certain orders.

I also see robots being used more prominently in the future, whether exploring environments that are unsafe or inaccessible to humans, or working alongside humans. For this to be possible, the robots need to be able to deal with a lot of unknown scenarios that are very difficult to prepare for without the ability to learn and adapt.

To see Patricia's winning photograph, and all of the winners of the EPSRC Science Photo Competition, go to: EPSRC Flickr.

About iCub™

iCub™ is a humanoid robot developed by the Italian Institute of Technology and used in more than 20 laboratories worldwide. It has 53 motors that move the head, arms & hands, waist and legs.

Able to both see and hear, the robot has been specifically designed to support research in embodied artificial intelligence. At 104 cm tall, the iCub is the size of a five-year-old child. It can crawl on all fours, walk and sit up to manipulate objects. Its hands have been designed to support sophisticated manipulation skills.

The iCub is distributed as Open Source and can now count on a worldwide community of enthusiastic developers. More than 30 robots have been built so far which are used in laboratories in Europe, the UK, the US, South Korea and Japan.

About EPSRC

Total value of EPSRC's research and training portfolio:	£4.6 billion
Percentage of research portfolio that is multidisciplinary:	56%
Total invested in research and training annually:	£800 million
Organisations involved in collaborative EPSRC grants:	Over 3,553
Percentage of research portfolio that is collaborative:	54%
Total leveraged from users:	£1.1 billion

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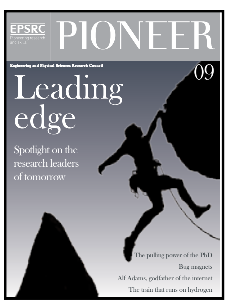

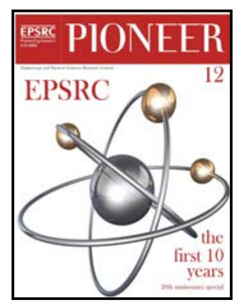

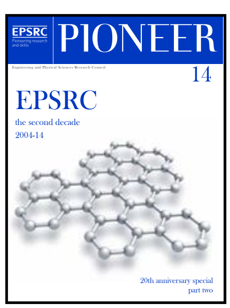

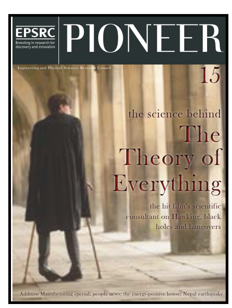

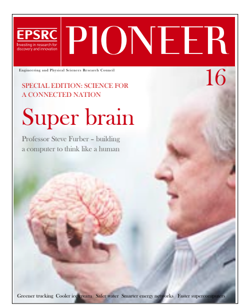

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