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SEPTEMBER 2017 ISSUE 72

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The Arcadia Spider entertains festivalgoers at Glastonbury 2017 © SHOTAWAY

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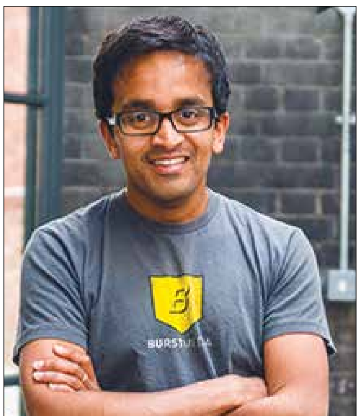

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EDITORIAL

PARITY OF ESTEEM IN CAREER PATHWAYS

Dr Scott Steedman

For every profession, bridging the gap between school and employment is fundamental to securing skills for the future. In engineering, for many decades the emphasis has been on academic degrees as the primary route to qualification and a career. Technical pathways into engineering, such as apprenticeships, were widely perceived as less prestigious. Showcase events and the promotion of qualifications for incorporated and technician engineers have had minimal impact on the numbers and diversity of school leavers taking up engineering careers.

Meanwhile, the skills crisis in engineering grows as employer after employer highlights the shortage of recruits as a major risk to future growth. Recent initiatives to increase the number of apprentices across the country try to present an alternative route into employment. A hybrid approach, whereby those in work can pursue academic study through engineering degree apprenticeships, is now offered as a new pathway to achieve the same standard of educational qualification. The possibility of gaining a degree while working, and potentially avoiding a large student loan, may entice some recruits but it will take a fundamental shift in the public perception of engineering to address the shortfall across the country.

The Spring Budget heralded a further impetus for change when the Chancellor announced the new T-levels, an idea proposed in 2016 by Lord Sainsbury in his independent review of technical education for the then Department for Business, Innovation and Skills and the Department for Education, the recommendations of which resulted in the *Post-16 Skills Plan*. T-levels will offer a new form of post-GCSE technical qualification in 15 areas, including engineering and manufacturing, construction and digital skills, and work placements will complement college-based teaching.

So, looking top down, major new developments are in the pipeline. Will they deliver?

Evidence from Greater Manchester and Leeds City Region published this year in an OECD-ILO report, *Engaging Employers in Apprenticeship Opportunities*, highlights the importance of working locally to promote apprenticeships and engage employers. Both studies also highlighted the importance of creating a single, independent central advice service to replace myriad existing national and local initiatives. Salaries and quality of apprenticeships were also seen as critical, as is the potential for career progression.

One finding in the OECD-ILO report from case studies in Germany, which the UK should learn from, is that the involvement of employers in the provision of vocational education is essential to maintaining the quality of apprenticeships. In Germany, this means employers influencing the development of curricula at federal level and working closely with regional and local organisations to ensure that their needs are aligned with young people's expectations. The attitude of teachers will be critical if they are to persuade students that employers will attach equal prestige to the technical and academic pathways into engineering, called 'parity of esteem'. This is not a new challenge, but one also highlighted by the OECD-ILO report and independently by the Engineering Professors Council (EPC) in its current review of degree apprenticeships, which has highlighted the importance of improved and impartial careers advice and guidance in schools. For engineering careers in particular, where teachers and careers advisors rarely have industry experience of their own to draw upon, it is vital that the profession provides attractive and informative training. STEM Learning, based at the University of York, is one example of an initiative aimed at doing just this through the provision of continuing professional development for teachers and support staff.

Changing public perceptions, and encouraging more young people to take up engineering, is at the core of the Royal Academy of Engineering's purpose and is central to addressing the skills shortage. Employers must get engaged, but so too must the profession through the Academy, the professional engineering institutions (PEIs), the Engineering Council and EngineeringUK. Simple messages, agreed by all and communicated identically, that aim to create parity of esteem are essential to support the efforts of employers and agencies across the country. This needs an holistic, cross-sectoral approach to the promotion of technical and academic educational pathways to employment. With the support of the council and the PEIs, pulling this together with central and local government must be an Academy priority.

Dr Scott Steedman CBE FREng
Editor-in-Chief

IN BRIEF

ENGINEERING AWARD WINNERS

Roma Agrawal, winner of the Royal Academy of Engineering's Rooke Award, in front of The Shard, London. She spent six years working on the building as senior structural engineer © WSP

In June, the Royal Academy of Engineering hosted its annual Awards Dinner, which celebrated and recognised a number of engineers who have made a remarkable contribution over the course of their careers.

Roma Agrawal, a structural engineer and Associate Director at AECOM, received the Rooke Award for her outstanding contribution to the public promotion of engineering through her talks and television appearances. Over the last six years, she has spoken to over 10,000 people at hundreds of events in the UK and abroad and has appeared in magazines such as *Stylist*, *Cosmopolitan* and *Glamour*, which do not commonly feature engineers. Roma has also written articles for the *Guardian* and the *Daily Telegraph*, and appeared on documentaries for the BBC, Channel 4 and Channel 5. Her first book, *BUILT: The hidden stories behind our structures*, will be published in February 2018.

The Major Project Award was presented to a team from Arup for its work on Glasgow's SSE Hydro Arena, which is Scotland's largest entertainment venue. The Arup team had to overcome significant challenges to create the building situated on the bank of the River Clyde, such as difficult ground conditions, with the biggest being the design and installation of a 125-metre clear span, tilted roof.

The President's Medal was awarded to Ian Shott CBE FREng in recognition of his many contributions to the Academy's work. This includes his role as founding Chair of the Academy's Enterprise Committee, which culminated in the successful establishment of the Enterprise Hub – an incubator that provides funding, business support and mentoring to engineering and technology startups.

Five young engineers received the RAEng Engineers Trust Young Engineers of the Year awards: Dr Ruth Misener, a lecturer in computational optimisation at Imperial College London; Frank O'Leary, a geotechnical engineer at Arup; Anna Polszajski, an engineering doctorate candidate at UCL; Chris Shaw, lead engineer at game developer Sensible Object; and Dr Jenni Sidey, a lecturer in combustion at the University of Cambridge. Dr Ruth Misener was the winner of the Sir George Macfarlane Medal for her work in developing innovative approaches to process systems' engineering challenges using the latest computer science techniques. The medal is awarded to engineers who have demonstrated excellence in the early stage of their careers.

The winner of the MacRobert Award, Raspberry Pi (see page 24), and the five Silver Medallists (see page 38) were also announced.

REPORT CALLS FOR ACTION ON INCLUSION

The Royal Academy of Engineering has released the results of a unique study of diversity and inclusion across the engineering profession, based on survey responses from 7,000 UK engineers.

The aims of the survey, which was undertaken in January 2017, were to increase understanding of the culture of engineering, the extent to which it is inclusive, and what would make it more so.

The survey found that there is a strong business case for inclusion within the profession. Respondents to the survey who felt included reported increased motivation (80%), performance (65%) and commitment to their organisation (52%). The responses showed that the more included engineers feel in an organisation, the more likely they are to understand business priorities, see a future for themselves in the profession, and feel more confident to speak up about improvements, mistakes or safety concerns. These benefits were not only reported by women and ethnic minority engineers, but also by white male engineers, who make up the majority of the profession.

To make progress, the report highlights the need for action from engineering leaders, managers, human resources and communications staff, as well as individual engineers, in areas such as: prioritising inclusion; better articulating the benefits of inclusion; increasing awareness of how different groups perceive workplace culture; and monitoring data on the delivery of career support and talent management.

To read the full report based on the survey responses, please go to **www.raeng.org.uk/engdiversity**

SECRETS OF HISTORY AT *INGENIA LIVE!*

Injuries found on Richard III's skull were analysed to identify what caused his death © University of Leicester

In September, the latest *Ingenia live!* event will explore how engineering techniques have helped to reveal the secrets of history.

Taking place at Prince Philip House on 26 September, the event will host talks on real-life case studies from Professor Sarah Hainsworth FREng, Professor Mark Williams and David Mearns.

As former Professor of Materials and Forensic Engineering at the University of Leicester and a specialist in her field, Professor Hainsworth will discuss how forensic engineering science helped to discover how Richard III died on the battlefield, after his remains were found under a Leicester car park in 2012 ('Solving a historical mystery', *Ingenia* 71). Professor Mark Williams, Project Evaluation Technologies Group Leader and Principal Investigator, Warwick Manufacturing Group, University of Warwick, will explain how his team's technologies and expertise have helped solve serious crimes ('Digital forensics', *Ingenia* 66), and even found new teeth in a dinosaur fossil that is more than 200 years old. David Mearns is a marine scientist and oceanographer, and will talk about work he has done with Professor Williams using cutting-edge manufacturing to identify a rare silver coin that was found in a shipwreck off the coast of Oman.

The event will be chaired Dr Scott Steedman CBE FREng, Editor-in-Chief of *Ingenia* and will be followed by a Q&A session and a networking reception.

Ingenia live! brings to life the stories featured within the magazine, covering a whole range of engineering disciplines and providing an opportunity for live interaction.

Tickets cost £10 and students can attend free of charge. To register, please visit **www.raeng.org.uk/ingenia2017**

DISCOVER STEM AT *NEW SCIENTIST LIVE*

Between 28 September and 1 October, the second *New Scientist Live* will take place at ExCel London. A celebration of science, technology and engineering, the event will have interactive demonstrations, exhibitions and speakers across five zones: engineering, cosmos, earth, humans and technology.

The engineering zone is a new addition to the event, which will demonstrate the breadth of engineering and feature talks covering everything from robotics and space craft design, to solar farming and self-healing cities. The Royal Academy of Engineering's *Star Wars* themed stand will explore the latest advances in robotics, haptics and more. The stand will demonstrate how life can now imitate the art of *Star Wars* thanks to engineering innovation.

Speakers at the event include author Margaret Atwood, astronaut Tim Peake, founder and CEO of DeepMind Demis Hassabis, and Director of UCL's Institute of Making Professor Mark Miodownik FREng.

For more information and to book tickets, please visit **www.newscientistlive.com**

The Royal Academy of Engineering's *Star Wars* themed stand at *New Scientist Live* will explore the latest innovations in robotics © David James

IN BRIEF EXTRA

MISSION TO REMOVE SPACE DEBRIS

In early 2018, the first experiment to test technologies to remove space debris in low Earth orbit is expected to launch.

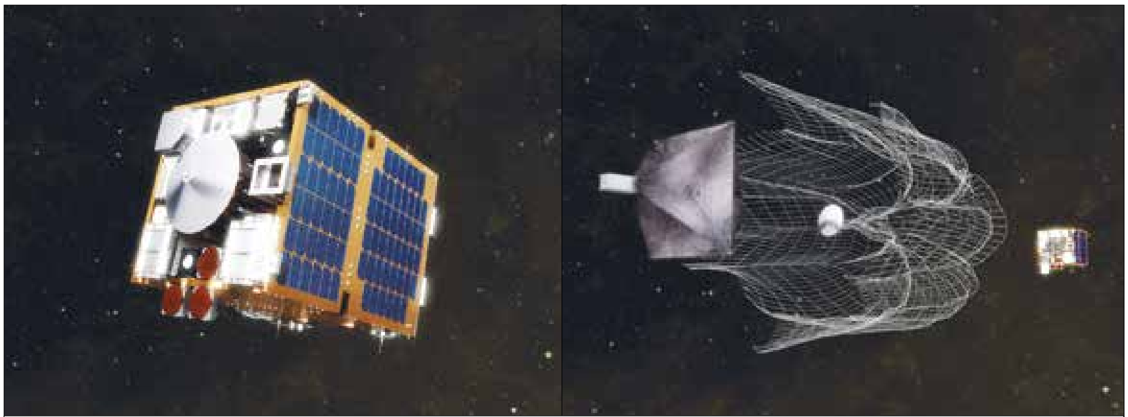
The RemoveDebris mission has been developed by a consortium of institutions led by the Surrey Space Centre at the University of Surrey and is a €15.2 million project partially funded by the European Union. The mission will employ both a net and a harpoon system, neither of which have been tested in space before, to capture space junk – fragments of damaged satellites or rockets in orbit that can then collide with other spacecraft and cause further wreckage.

An artist's impression of the amount of space debris in low Earth orbit, viewed over the equator © ESA

AN ENVIRONMENTAL CRISIS

October 2017 will be the 60th anniversary of the launch of Sputnik, the first ever satellite. In the six decades that humans have been exploring space since, it has become increasingly full of clutter, and experts are now worried that the orbital environment is becoming unstable. According to Holger Krag, head of the Space Debris Office at the European Space Agency (ESA), there are roughly 5,000 objects larger than one metre, 20,000 objects larger than 10 centimetres, 750,000 objects around one centimetre and around 150 million objects around one millimetre that are currently in low Earth orbit. Out of all of these objects, only 1,200 are operational satellites. The rest are defunct craft, used rocket stages and, mostly, fragments created in collisions. The US Space Surveillance Network currently tracks about 18,000 objects larger than 10 centimetres and issues conjunction warnings to spacecraft operators in case their satellites are on a collision course with pieces of debris.

At the Seventh European Space Debris Conference in April 2017, American astrophysicist Donald Kessler said that 10% of all satellites in low Earth orbit experience small collisions with space debris, causing immense financial risks to the operators. It was Kessler who first predicted in 1978 that a situation would occur where collisions between fragments and satellites would become unstoppable. The phenomenon now bears the American's name – the Kessler Syndrome. According to Krag, the first indications of Kessler Syndrome are already occurring. However, modern civilisation is increasingly reliant



An artist's impression showing the RemoveDebris spacecraft and the net that it will employ to catch space debris
© Surrey Space Centre

on space assets. The world needs satellites for a number of activities, from navigation to weather forecasting and telecommunications.

International guidelines currently recommend that operators should remove satellites from low Earth orbit – the altitude up to 2,000 kilometres – within 25 years after a mission has ended. Only 60% of operators currently meet the requirement as it involves a complex manoeuvre that takes place when the satellite already has a long mission behind it.

Now, spacecraft engineers are developing technologies that could help with the orbital clean-up, such as dedicated deorbiting thrusters that could steer satellites into the atmosphere to burn up within weeks, or sails that are deployed at the end of the mission and increase atmospheric drag to speed up the deorbiting process.

CATCHING SPACE JUNK

For the purpose of the RemoveDebris experiment, the debris collector craft will carry its own pieces of debris – CubeSats (mini satellites that are the size of a shoebox) – to release and catch. This is because the current legal framework does not allow people to remove debris that belongs to someone else. Even if no longer functional, the broken spacecraft still belongs to its original owner and no one is legally allowed to move it.

The RemoveDebris spacecraft, weighing about 100 kilograms, will be the largest item to have ever been pushed to space directly from the International Space Station. Once freely in orbit, the catcher spacecraft will release the first of its targets. Springs will push the CubeSat out of the spacecraft's door into orbit and, at a set time, the net will then recapture the mini satellite. Although this sounds simple and has been extensively tested on Earth, it has never been demonstrated in space, which is a much harsher environment.

In future missions, the net will be connected to the catcher craft by a tether so that debris could subsequently be dragged down into the atmosphere using its thrusters. However, for the purpose of the demonstration, the RemoveDebris team decided to leave the tether out to avoid the risk of problems such as the CubeSat bouncing back and hitting the mission's main satellite.

A second CubeSat will be used to test a vision-based navigation system that would allow two spacecraft to safely meet in space. The system, consisting of a LIDAR (light detection and ranging – a remote sensing method that uses light in the form of a pulsed laser to measure variable distances to the Earth) and an optical camera, would track the CubeSat as it drifts away from the main craft. Data will be collected via a satellite link to determine whether the system is working correctly.

Eventually, the main craft will deploy a boom with a fixed plate, into which it will subsequently fire the harpoon. In future missions, the aim is for the harpoon to be fired into a piece of space debris, but the technology is still being developed. A large sail will then be employed to speed up the deorbiting process, so that instead of the recommended 25 years, the debris would burn up in the atmosphere within a year or two.

The RemoveDebris mission will help engineers learn valuable lessons and advance the technology before they move towards larger and more expensive missions.

ESA hopes to use the lessons learned from RemoveDebris in the eDeorbit mission, an ambitious project to remove a defunct 8-tonne satellite from low Earth orbit in the mid-2020s. Its engineers currently envision that the eDeorbit craft could use a net or a robotic arm to capture the observation satellite Envisat, which stopped responding to ground controllers in April 2012. The satellite is currently at an altitude of 700 kilometres above the Earth's surface and is estimated to take 200 years to deorbit. During that period, between 15% and 20% of the satellite could collide with other debris – or higher if more satellites are launched.

To find out more about the RemoveDebris mission and follow its progress, please visit **www.surrey.ac.uk/ssc/research/space_vehicle_control/removedebris**

Words: Tereza Pultarova

HOW I GOT HERE

Q&A

LUCY HARDEN
MECHANICAL ENGINEER

Lucy Harden is a mechanical engineer on BAE Systems' Digital Light Engine Head-Up Display development programme. She devises innovative solutions for pilots using computer-aided design (CAD) to display essential flight information that sits directly in their line of sight and is overlaid onto the real world.

WHY DID YOU FIRST BECOME INTERESTED IN ENGINEERING?

I was very lucky to have some amazing teachers at school who encouraged me to stick with STEM subjects until my A levels, but I wasn't really sure where they could take me in a career. When I was younger, engineering was the last career I thought I'd get into. I have always been very creative and I wanted to go to drama school to act or be involved in costume design or lighting. Looking back now, building things with LEGO and my love of textile design, combined with the skills I had in maths and science, were the foundation of a career as a mechanical engineer. I always loved watching programmes such as *Scrapheap Challenge* and *Brainiac*, which showed me how science can be applied to real life.

HOW DID YOU GET TO WHERE YOU ARE NOW?

I ended up taking quite a large selection of A levels at school, purely because I was still unsure of what career to choose. The turning point was being advised by a teacher to take part in the Engineering Taster Week at BAE Systems, a week-long programme where I learned about engineering and fell in love with it. After graduating, I joined its Graduate Development Framework scheme where I was able to work on a variety of projects and product lines.

WHAT HAS BEEN YOUR BIGGEST ACHIEVEMENT TO DATE?

I have been lucky in my career as I have been given so many opportunities to succeed. I think my biggest achievement to date was winning BAE Systems' 'Technical Graduate of the Year' award during my first year on the scheme. I am also incredibly proud of the work we did with UK Sport, where we won an internal Chairman's Award. I worked on a large range of projects, including one with the Great Britain cycling team's BMX squad. That project involved using BAE Systems' cutting-edge optical sensor technology, which was originally developed for unmanned-aircraft. The sensors interact with miniature LEDs on the BMX bikes to track the trajectory of the riders while on the ground and, critically, in the air. This information is then relayed to a specially designed app, giving riders and coaches a real-time read-out of performance, so that they can identify where they can make critical marginal gains. I watched the Rio Olympics with a huge sense of pride last year knowing that I had worked to provide engineering solutions to some of the sport's biggest challenges.

WHAT IS YOUR FAVOURITE THING ABOUT BEING AN ENGINEER?

One of my favourite things about being an engineer is seeing a rough concept design on a piece of paper turn into something that is physically in your hands and then on an aircraft, flying. I have had the opportunity to meet the end-users of some of our products; it is always amazing to hear how I personally have helped to solve a problem for a customer. I also really enjoy going to schools as an education ambassador where I teach children how science and maths relate to their lives, and how important it is that they stick with those subjects in school. Some of them have come back to complete work experience at BAE Systems, which is really motivating.

WHAT DOES A TYPICAL DAY AT WORK INVOLVE FOR YOU?

I generally start my day by assessing the week's schedule and ensuring that the team is on track against progress milestones and budget. My morning will typically consist of project team update meetings, where we run through each engineering discipline's tasks and discuss any challenges or opportunities that have arisen. I will then spend the rest of my day working through the aspects of the overall design scheduled for that week, using CAD to turn my ideas into reality. I also have to analyse my design, which may include performing a tolerance analysis to make sure everything interfaces correctly.

ARE THERE ANY CUTTING-EDGE TECHNOLOGIES THAT YOU WORK WITH?

While on the graduate scheme, I had the opportunity to work on a product called Striker II, a helmet-mounted display system for fighter pilots. This is a digital helmet that allows pilots to fly with their 'heads up and eyes out' by projecting flight critical information directly onto the helmet's visor. This means that while the pilot is conducting fast manoeuvres or evading threats, they do not need to look down at displays in the cockpit to get the information they require. One of the most interesting things for me, from a mechanical engineering perspective, was ensuring that the design was not only cutting edge, but that it provided pilots with the high level of capability and protection that they need to return home safely.

Lucy representing BAE Systems at the 2016 Farnborough International Airshow, where she demonstrated the head-up display technology

WHAT WOULD BE YOUR ADVICE TO YOUNG PEOPLE LOOKING TO PURSUE A CAREER IN ENGINEERING?

Keep going with your STEM subjects! I would also recommend work experience within an engineering company to find out what a typical day looks like for an engineer. There are various engineering companies in the UK that cover a wide range of sectors; I'm sure there will be something of interest for everyone who is considering a career in the industry. I would also recommend becoming a young member of your relevant professional institution, which can provide advice and information on what is going on in the industry. It is also a great way of networking and can sometimes lead to finding a mentor to assist with your career development.

WHAT'S NEXT FOR YOU?

Within work, achieving our main mechanical design milestones for the product I am currently working on. My next main personal goal is to try and gain professional registration as a chartered engineer with the Institution of Mechanical Engineers, and become a mentor for young engineers to assist with their early career development.

QUICK-FIRE FACTS

Age: **25**

Qualifications: **MEng Mechanical Engineering (Hons)**

Biggest inspiration: **Richard Branson**

Most-used technology: **probably my iPhone**

Three words that describe you: **driven, outgoing and enthusiastic**

OPINION

WHAT ROLE FOR BIOFUELS IN LOW-CARBON UK TRANSPORT?

Biofuels have a role to play in meeting the UK's commitments to reducing climate change. Professor Adisa Azapagic FREng, Professor of Sustainable Chemical Engineering at the University of Manchester, sets out why biofuels made from wastes and by-products in different sectors are particularly important to these efforts.

Professor Adisa Azapagic FREng

The mobility of people and goods is a key enabler of all social and economic activity. However, mobility comes at an environmental cost, including emissions of greenhouse gases (GHG) and related climate change impacts. With the UK Climate Change Act committing us to carbon reductions of 80% (on 1990 levels) by 2050, the transport sector needs to play its role in decarbonising our economy.

The quickening pace at which passenger transport is being electrified is a significant development that will likely be accelerated by recent government plans to ban the sale of new diesel and petrol cars by 2040. Provided we can decarbonise electricity generation – and build enough power stations to cope with the 'electric revolution' – this should prove a positive step. However, the electrification of passenger vehicles on our roads will take years and hybrid vehicles are likely to feature heavily in passenger transport, with liquid fuels continuing to play a role as a range extender. Perhaps more crucially, transport is much more besides just passenger road transport: aviation, shipping and haulage are all significant parts of the transport system. They have much more limited options for low-carbon energy so will have to rely heavily on liquid fuels for the foreseeable future. This all points to a need for low-carbon liquid fuels.

To address this issue, the EU Renewable Energy Directive (RED) introduced mandatory targets for member states to ensure that a 10% share of transport energy is from renewable sources by 2020. In the UK, the RED is implemented through the Renewable Transport Fuels Obligation, which mandates a total supply of biofuels in road fuel sales. Currently, this is sitting at 4.75% (by volume), some way off the 10% target.

Biofuels are liquid fuels derived from different biomass feedstocks. These include food and feed crops (such as corn, wheat and sugar cane), energy crops (such as willow and *Miscanthus*) and biodegradable wastes (such as agricultural, forestry and food).

However, since the introduction of the RED, biofuels have been dogged by controversy and their sustainability has been questioned. Principal among the sustainability concerns include:

- Socioeconomic impacts of diverting food crops into fuel production, including food security in some parts of the world.
- Indirect land-use change (ILUC): a change in the purpose for which land is used occurring indirectly as a result of the need to grow more biofuel crops elsewhere to satisfy pre-existing demand for food, feed and other agricultural products. Among other effects, this increases GHG emissions since soils and vegetation contain large stocks of carbon that, when disturbed, can be oxidised and released to the atmosphere as carbon dioxide. While direct conversion of previously uncultivated land for the production of biofuel feedstocks is prohibited by the RED, ILUC is currently not regulated.

I recently chaired a study by the Royal Academy of Engineering, requested by the Department for Transport and Department for Business, Energy and Industrial Strategy (previously Department of Energy and Climate Change), which conducted a comprehensive review of the sustainability of biofuels and the methodologies by which this is assessed and accredited. So what did the report find in relation to the concerns above?

On the 'food versus fuel' issue, the review concluded that the notion that biofuels production competes directly with food production is at best an oversimplification. Provided there are mechanisms for prioritising food markets when needed, the addition of a biofuels market can actually benefit the agricultural sector, providing an extra incentive to plant crops and diversifying farmers' income, investing in process efficiencies and crop yields, and improving the infrastructure. This is not to say that the potential for competition with food does not need to be carefully managed, especially in areas of the world that experience food scarcity; however, it is rarely a black and white choice between food or fuel.

The report also found that ILUC caused by biofuels from food crops is a legitimate concern; it has almost certainly occurred and when it does, it can significantly increase the carbon footprint of biofuels. The tricky part is establishing the causal link between the production of biofuels from a food crop in one part of the world and an increase in production from newly converted land in another. However, since these concerns have come to light, much work has gone into understanding indirect market effects from biofuels demand and identifying the biomass feedstocks that pose a risk of ILUC. We have also seen a move in biofuels policy away from food crops towards using wastes and residues for biofuels production. As a result, almost 60% of biofuels supplied in the UK are now produced from wastes and non-agricultural residues. These include waste from the food and drink sector, with used cooking oil from restaurants and the catering industry being a predominant feedstock. Other examples include tallow and sewerage oils and greases while, in the future, there are opportunities to produce biofuels from agricultural and forestry residues.

Based on the findings in our report, we ultimately conclude that the UK government can and should increase the levels of biofuels required in our transport fuels. However, some crucial steps must be taken to adequately manage the risks involved. Key among these are:

- Avoiding over-incentivising biofuels from food and other land-based crops (and the associated risk of ILUC) by:
  - setting a cap on the supply of all crop-based biofuels
  - continuing to incentivise the development of biofuels derived from, in the first instance, wastes and agricultural, forest and sawmill residues, followed by dedicated energy crops.
- Strengthening the current audit and accreditation schemes by:
  - ensuring the full traceability of waste feedstocks to verify that they are genuine wastes and not diverted from some other, more valuable use
  - ensuring that all relevant socioeconomic impacts are fully considered and addressed.

An uplift in biofuels production will enable industry to build on its existing capacity in order to develop the advanced, low-carbon fuels needed in key sectors, such as aviation, shipping and haulage. In short, provided the necessary steps laid out in the report are taken, biofuels can and should play a role in a low-carbon future for UK transport.

BIOGRAPHY

Adisa Azapagic FREng is Professor of Sustainable Chemical Engineering at the University of Manchester. Her research focuses on applying principles of sustainable development and lifecycle thinking in industrial practice. Adisa chaired the Academy's study referred to in this article.

The Academy's report, *Sustainability of liquid biofuels*, was produced by a working group of Fellows and experts, supported by Academy staff.

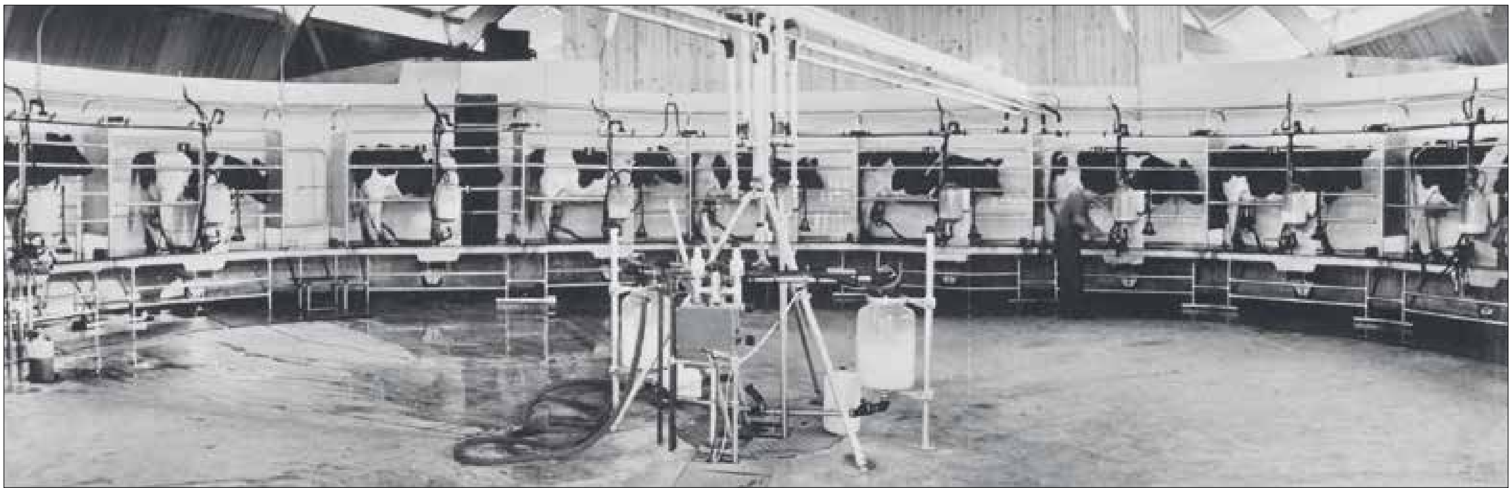
A copy of the report can be found at **www.raeng.org.uk/biofuels**

THE AUTOMATION OF DAIRY FARMS

Automated milking systems are being developed to do much more than just milk cows. Newer systems can test the milk's quality, monitor health and fertility, and feed in to a centralised computer system for the whole farm © pixabay.com/skeeze

Robotic milking is not a new innovation, but the systems are increasingly being adopted by UK dairy farms. Science writer and broadcaster Geoff Watts learned from John Baines, Technical Director at Fullwood, how these systems are being engineered to do more than just milk cows.

There is something faintly incongruous about the sight of a dairy cow ambling through a farmyard, entering a barn and, at its own volition and at a time of its own choosing, stepping into a robotic milking machine. Cows are herd animals that mostly follow the actions of the group or, more often, their human herder. The agricultural engineers who first dreamed up the idea



While early milking parlours were mechanised, dairy farmers still had to herd the animals into the machines and attach teats. Cows can enter the automated systems at their own volition and the teats are typically attached by a robotic arm © Royal Association of British Dairy Farmers

of robotic milking machines seem, quite unintentionally, to have given cows an autonomy that allows each one to make decisions for itself.

Robotic milking is still relatively uncommon in the UK, where only around 10% of farms already use the systems and they constitute around 30% of all new milking systems being purchased. However, robotic milking is a proven technology and it has become a core element in a more recent and still expanding web of technologies that are bringing a new rigour to the business of dairy farming. Instruments that can be bolted on to the milking robot, or otherwise used in conjunction with it, are now offering farmers a more complete picture of their livestock: their animals' health, fitness and fertility, and the quality of the milk they produce.

As a recent report on the state of the dairy industry pointed out, farming is not noted for the speed or enthusiasm with which it has embraced technology. Mechanisation has brought larger tractors and replaced muscle power with machine power, but it has only been near the forefront in one area – the use of GPS to guide unmanned tractors. The industry has now started to adopt automation and begun assembling networks of machines that are able to talk to one another; the internet of things seems set to bring radical changes to the business of dairy farming.

AUTOMATED MILKING

In the short history of robotics, there are few instances of successful interactions between a robot and a living creature. There are fewer still where engineers have designed a machine that is able to take account of biological and behavioural variability in establishing contact between the two parties, which is what milking robots have achieved. The goal was not reached overnight, and today's robots are the product of developments that began several decades ago. Their exact form and method of operation depends on the manufacturer, but the similarities are greater than the differences.

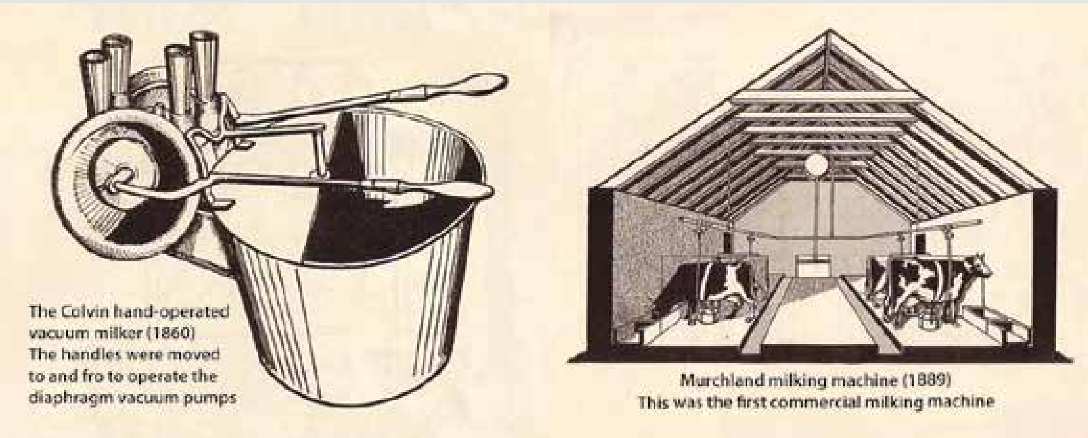
Besides the design problems familiar in the development of any new machine, engineers who devise robots for use with agricultural livestock have to bear in mind that it will operate in an exceptionally mucky environment. The machines have to be animal friendly: robust enough to withstand the occasional kick, but gentle to the animal. The pneumatic or electrical drives that power the sections of the robot that have direct contact with the animals have to be sensitive to any opposing force. The chosen parameters will vary from one function to another but, generally speaking, the rule is to push firmly but lightly, and to back off when experiencing sustained resistance.

The equipment usually comprises a tough stainless steel stall that is slightly wider and longer than the animal, and has gates at both ends. The cow enters the empty stall, lured by a feeding trough mounted on the closed head-end gate, while a photocell detects the animal's presence and the rear gate closes. The cow's identity is established by an electronic ankle, neck or ear tag.

With the cow in place, food starts to pour into the feeding trough from an overhead machine. The cow is likely to keep relatively still while it concentrates on eating. The central portion of the stall's floor is covered with a grid to ensure that the cow stands with its back legs set conveniently apart and adjacent to the sides of the stall.

The robot's arm is mounted outside the stall and below

EARLY ATTEMPTS AT ROBOTIC MILKING



Although not robotic, innovative engineering was employed in the Colvin hand-operated vacuum milker in 1860 (left) and the first commercial milking machine developed by Murchland in 1889 (right) © Fullwood

The engineers who originally set out to automate milking faced several challenges. The first was simply to get the cows' cooperation. This proved relatively straightforward as with most animals, food is a powerful inducement. A second, and more demanding hurdle, was to devise a means by which the robot could identify the position of the cow's teats and bring its four suction cups into correct alignment with them. The 1990s saw a variety of attempts, some that never left the drawing board and others that began to overcome the obstacles step by step.

For example, a report issued by the Silsoe Research Institute in 1993 outlined the technology used by one prototype milking robot to tackle the attachment problem. The robot relied on three sources of information. First there was 'stored knowledge' that was derived by initially guiding the robotic arm bearing the teats manually into place, and having the machine memorise the relevant coordinates. Added to this was 'inferred knowledge' of the teat position, which was obtained from knowing the body position of the cow as assessed by "linear potentiometers, which are fitted to the stall and connected to links held in contact with the cow by pneumatic cylinders". There were two sets of this equipment: one to detect any longitudinal movement of the animal and the other to detect lateral movement.

The robot's third source of information came from a matrix of light beams generated by infra-red light-emitting diodes that crossed the interior of the machine's teat-cup holder to impinge on an array of detectors. "A teat entering the matrix obstructs one or more of the beams causing the robot to move until the teat is centred over the teat-cup holder, which the robot then raises for attachment."

The performance of this system was not altogether impressive. In one test of 10 cows involving 1,440 attempted teat-cup attachments, almost a fifth were unsuccessful. A different approach relying on ultrasound guidance of the robotic arm was also found wanting. It was the introduction of more sophisticated optical tracking, especially with lasers, that made robotic milking the practicable and effective technology it has since become.

udder level, where it can swing horizontally into the stall, beneath the animal's belly, and move unhindered between the front and back legs. Using stored xyz coordinates to locate itself in roughly the required position, the arm first cleans the cow's teats using a water spray and pair of soft rotating brushes that can help trigger the release of the hormone oxytocin into the cow's circulation, which produces the milk.

Alignment of the robotic arm's four suction cups below the cow's teats calls for more accuracy than the cleaning that preceded it. This extra precision is achieved by a laser or similar optical tracking system directed to the teats. It has to cope with a target that is anatomically variable and prone to move as the cow breathes or shifts the position of its body within the stall. The tracking system guides one of the cups to its correct location and then pushes it up on to the teat. Suction pulls it firmly into place and holds it there. The same procedure is repeated for each of the other three cups.

A vacuum sensor located in the tube carrying milk away from the robot signals that the cup is attached. However, the cup might be hanging on to the skin of the udder and not to the teat itself. If this happens, a liquid flow sensor that is electrochemically activated by the presence of milk will fail to send the expected signal and the cup will be

Cows are encouraged into the automated milking stall by a feeding trough at one end. The rear gate closes when the animal's presence is detected by a photocell, which also records the cow's identity via an electronic tag © Fullwood

A robotic arm in the milking stall uses stored coordinates to locate the position of the cow's teats, which are then washed by soft brushes on the arm. A laser tracking system is then also employed to improve more accurate positioning of the suction cups © Fullwood

detached for a second attempt. The milk sensors also respond when the flow from each teat has ceased. One by one the cups are pulled off, the teats are sprayed with disinfectant, the robotic arm retracts, the front gate of the stall opens, and the cow is free to go.

MILK QUALITY

Besides collecting milk, the robot's inbuilt instrumentation can run a series of checks on its quantity and quality, the latter including its fat, protein and carbohydrate content. Optical scanning reveals the presence of any blood that might render it unfit and therefore to be rejected. Data on all aspects of every milking for every cow is collected by the robot and transmitted to the farm computer. Farmers can scrutinise them as and when convenient, and in as much detail as necessary to understand the performance of each cow in the herd.

Analysis of the milk may point to particular nutritional deficiencies in some animals and this can alert the farmer to take remedial action when feeding the cow during milking. The robot could even act on its own initiative if given appropriate instructions. The robot can also make choices about the path to be taken by the cow as it leaves the milking stall. With appropriate gating technology, each cow can be allowed to return to the barn or the field, or be automatically diverted to a pen for a particular purpose, such as a veterinary inspection.

FERTILITY AND HEALTH

Automated milking offers the opportunity for monitoring each cow's health and fertility. It is a feature that already exists in most systems and seems set to grow. Farmers need to know which cows are ready to breed and when because milk production, which starts when a cow calves, ceases after 10 to 12 months, so the cow must breed again to restart the flow. Cows are also only receptive to insemination for a brief period every 21 days, so timing is important. When cows are ready to breed, they become more active and their step count may increase by around ten times. The ankle or neck tag can be combined with a three-dimensional accelerometer to monitor the cow's activity. This is also critical to monitoring the animal's health as, for example, a cow that repeatedly gets up and lies down may be suffering some kind of discomfort.

The accelerometer can monitor and broadcast this movement continuously and in real time. However, if for some reason the cow has been beyond the range of the system, information stored in the tag can be downloaded when the cow makes its way back to the milking robot. Indeed, the milking robot offers a clutch of opportunities for health assessment. Further measures of the milk flow can flag up disease in the milk glands, such as the bacterial inflammation known as mastitis.

Online cell counting in milk has also been introduced to detect signs of mastitis. Some

A liquid flow sensor in the system that is electrochemically activated by milk can tell whether the cup is attached incorrectly and when the milk production has ceased, automatically allowing the suction cups to be removed. Inbuilt instrumentation can also run checks on the milk's quality and quantity © Royal Association of British Dairy Farmers

of the cells in question are shed from the cow's milk-producing tissues, but most are white blood cells that appear in increasing numbers in the milk when the animal has acquired one of the pathogenic microbes that cause mastitis. Cells are detected by the withdrawal of a small sample of milk from the stream, which is mixed with a dye to stain any cells present that allows a digital camera to count their number per unit volume of the milk.

The cell counts, for every cow at every milking, are also made available through the farm computer so that infected milk can be automatically diverted away from the main collection tank. The manufacturers claim that this system helps earlier detection, and earlier treatment, of even sub-clinical mastitis, and for the effectiveness of that treatment to be monitored.

Feeding has so far proved a less popular candidate for automation, but a minority of larger farms are already using it. Autonomous feed robots can be programmed to make their way along a preset route to a farm depot where the separate ingredients of the feed are loaded into them in the appropriate proportions. Having mixed them within its hopper while making its way back to the cows, the robot then moves along each row of animals dispensing feed in a predetermined amount. This allows the animals to be fed day and night.

THE FARM COMPUTER

The farm computer controls all of these devices and analyses the data that many of them collect. It is a focal point for all the accumulated information about each cow's health and wellbeing, and the milk that it is producing. Depending on the sophistication of the system, the computer can be programmed to act for itself in respect of individual animals.

Farmers new to this arrangement may fear being overwhelmed by the information that they can summon up on their screen, perhaps missing important insights amid a flood of data that will mostly be telling them that things are progressing satisfactorily. In practice, this overload can be avoided by prior selection of a normal range of values, with pre-determined alerts if those values are exceeded.

The most obvious benefits to the farmer of an automated system are the liberation it offers from the twice daily constraint of milking time and the need for close scrutiny of every animal for signs of disease. However, this latter advantage can also be seen as a drawback; good farmers know their cattle extremely well and may become aware of something that is not apparent to a machine. It is an argument that is already familiar in medicine, which has long since adopted vast amounts of diagnostic and monitoring technology. Doctors have found a middle way in which the use of technology stops short of total reliance on it and farming will surely learn similar lessons.

How the cows themselves feel about automation can only be inferred. It is claimed that milk yield tends to increase following the adoption of robotic milking, which can be an indication of contentment. Machinery that operates quietly, does not shout or wield a stick, and makes no unpredictable demands is certainly calculated to suit a cow's temperament.

THE TECHNOLOGICAL FUTURE

Where technology of this kind will go next is uncertain. Likely candidates for the future of automated milk testing are various reproductive and stress hormones and other yet to be identified biological markers of health and metabolic wellbeing. Less predictable is the role of novel gadgetry that exploits new observations about animals. For example, it seems that when sheep are suffering pain their eyes narrow, their cheeks tighten, their ears fold forward, their lips pull down and back, and the shape of their nostrils changes.

University of Cambridge scientists recently rigged up a camera linked to a computer running artificial intelligence

LAMENESS: A FURTHER OPPORTUNITY FOR NEW TECHNOLOGY

Bioengineers at the Royal Veterinary College (RVC) are among several groups to have experimented with automating the early detection of lameness in cattle. Affecting up to a third of dairy cows each year, lameness is not only a cause of pain but of reduced milk yield and lower fertility.

While early detection is self-evidently desirable, it is also time consuming and labour intensive because it relies on observation of the cows' movements and patterns of behaviour. Survey evidence suggests that many stockmen fail to notice what may be subtle indictors of the earliest signs that something is amiss.

Lameness alters a cow's normal pattern of walking, and the RVC team set out to exploit this in a machine designed to identifying such changes. Over a period of two years, they collected data on half a million foot strikes recorded from the sensors fitted to a series of force plates set at the exit from a milking parlour. This provided them with measurements of foot location, the vertical and horizontal forces involved, and other relevant features of every cow and the manner of its movements. Skilled observers also scored each cow for lameness using visual rating, and the team then compared their findings with those of the machine.

The researchers are confident that force plate analysis can pick up the early signs of lameness without human inspection. Their particular system has yet to be commercialised, but at least one other has recently come to market.

software that can identify and distinguish between these and more normal facial expressions. Their thought was to fit drinking troughs with the cameras, so that farmers would be alerted to any of their flock suffering distress that might otherwise have gone unnoticed. Whether cows display comparable changes of expression is a question for biologists, farmers and vets rather than engineers.

Even with another decade's worth of engineering advances, an image of a self-governing agricultural internet of things could be seen as fanciful. Although engineering ingenuity will continue to foster change, and not only in dairy farming. Current projects listed by the University of Lincoln's newly created Institute for Agri-food Technology include: an automated selective broccoli harvester; three-dimensional vision-based crop-weed discrimination for automated weeding; the autonomous control of agricultural sprayers; and the quantitative estimation of blemishes in potatoes using machine vision.

A recent survey described agriculture as among the world's least digitised industries, but the use of robots that collect data on the scale now growing apparent in the dairy industry is changing everything. Agricultural data analysis will become increasingly important in boosting the efficiency of the industry, and in planning its future. The popular notion of agricultural engineering as concerned largely with building bigger and better tractors is already out of date, and becoming more so.

MEASURING BODY CONDITION

The appearance of the hindquarters of a cow is a useful indicator of the adequacy or otherwise of its diet, which is a major influence on milk production. Farmers usually assess cows by eye, noting how their skin is either stretched tightly over the spine and pelvic girdle, or cushioned and rounded by an underlying layer of fat. Using a standardised five-point body condition scale they can score each cow, which can be more revealing than an animal's body weight alone.

Another recent addition to the health checks that can now be slotted into the pathway to or from the milking robot is the automated assessment of a cow's body condition.

At least one manufacturer has introduced new camera technology that aims to improve the accuracy and consistency of visual inspection. These systems rely on a short video sequence of the cow's hindquarters recorded by a camera mounted above a location that each animal must pass daily, such as the exit of an automatic milking machine. An infrared source on the camera directs a beam of light at the cow and technology in the camera's detector records how long it takes for reflections to reach it. The image-capturing process takes only seconds, and can be completed without the cow needing to stand still.

Software on the farm computer creates a 3D image of the cow's hind quarters from the data, and compares the contours of several areas with a set of standard surface contours seen on animals in conditions ranging from skinny and malnourished to overfed. The final result is presented by the computer as a score on the familiar five-point scale. A daily score for each animal's body condition allows its progress to be checked over time, and action to be taken if it falls outside pre-set limits. Such changes might be caused by a problem with the cow's health or the farmer might need to adjust feeding to take account of its position in the lactation cycle. Either way, the computer will automatically issue an alert.

BIOGRAPHY

John Baines has been Technical Director of Fullwood since 2003 and has been involved in the agricultural industry since graduating from the University of Aberdeen in 1977. John has been at the forefront of many projects including improving milking technology and introducing automation to the industry, as well as supporting milking system installations across the world.

For more than 70 years, a diverse range of musicians from Glen Miller and Cliff Richard to Radiohead, Coldplay and Lady Gaga have recorded albums at Abbey Road Studios. The expertise and cutting-edge equipment that was behind some of these albums is now being used by the next generation of pop stars © Abbey Road Studios

MUSIC FOR THE MASSES

Abbey Road Studios is one of the world's most famous recording studios, linked with some of history's greatest musicians and classic albums. Technology journalist Richard Gray talked to Mirek Stiles, Head of Audio Products at Abbey Road Studios, and Jon Eades, Head of Abbey Road Red, to learn how the studios' acoustic engineering expertise and classic equipment is being adapted to help today's DIY musicians.

With its herringbone-patterned wooden floor and lilac-coloured wall panels, it is easy to forget that at Abbey Road Studios you are standing in one of the most famous recording studios in the world. Studio One, at the heart of the studios in London, looks more like school gym hall than a place where music history was created.

The magic of the place is revealed when you close your eyes: the room has a wide, epic, acoustic feel that befits the orchestras that have played there. There is a slightly smaller space next door that boasts a warmer and more intimate sound, which has attracted some of the biggest musical artists in the world. Acts including The Beatles and Pink Floyd made many of their landmark recordings in Studio Two, as have more recent musicians such as Oasis and Adele.

The dimensions, wooden flooring and layers of wall panelling all contribute to the distinctive acoustics that emphasise the mid-range frequencies, making the studios perfect for recording pop songs. Many young and aspiring bands dream of being able to capture some of this sonic aura on their own tunes by recording here.

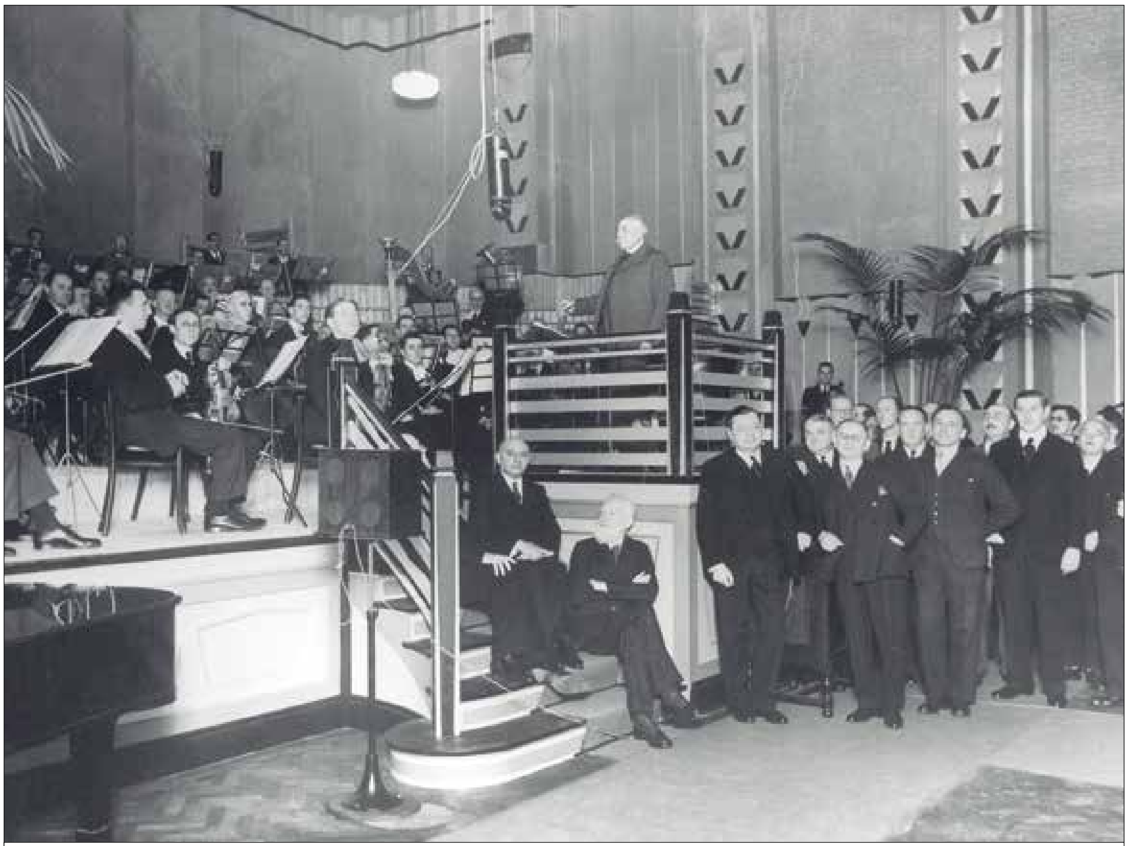
Today, however, the spread of cheap, high-quality software and digital recording equipment is removing the need for artists to book expensive studio time to produce their tracks. Technology is triggering a seismic shift in the music industry as new artists can record their music at home, without the need to rely on labels and large studios. Given this apparent threat to its business, Abbey Road is taking a somewhat curious approach, by helping these DIY musicians. Its engineers have spent the past five years developing software and online services that allow anyone with a home computer to recreate the distinctive Abbey Road sound in their bedroom.

WORLD FIRSTS

While this may seem an unusual step for an organisation whose business has been built around a special blend of the right venue, equipment and expertise, it is also characteristic of the rule-breaking experimentation that has been prevalent at Abbey Road since it first opened in 1931. Housed within a former nine-bedroom Georgian townhouse in north-west London, it was the world's first custom-built recording studio.

The studios were the first to use 'moving coil' microphones and recorders, which work by producing a small induced voltage in a coil of wire when sound waves hit a diaphragm, after they were introduced by engineer Alan Blumlein in the 1930s. He later developed the world's first stereophonic recording system at the studios. However, the arrival of The Beatles turned the studios into a household name when the band recorded Abbey Road there and the album cover featured a photo of the band walking across the pedestrian crossing outside. The 1960s and 1970s saw a flurry of experimentation as engineers hand-built tape machines, customised audio compressors and rewired recorders to automatically double-track performances. Tapes were sped up, looped, sliced and slowed down. Amplifiers were even placed inside cupboards to produce distinctive sounds.

Today, many rare pieces of equipment from this era sit in the corridors between the studios. The building has run out of storage space and the equipment is often still used by artists wanting to get a special vintage sound on their music.



Composer Sir Edward Elgar conducted an orchestra at the opening ceremony of the studios in 1931 on a stage built at one end of Studio One, demonstrating the sound and atmosphere of a live concert that the acoustic engineers hoped to capture © Abbey Road Studios

Engineer Gus Cook works with BTR-3 tape machines, one of which was rediscovered at the University of Southampton in 2016, in room 11 at Abbey Road Studios around 1965 © Abbey Road Studios

The warmth and character that is achieved by using signals through analogue circuits is still highly prized over the harsh ones and zeros of digital. It is perhaps fitting that this ageing analogue equipment is now playing a fundamental role in helping Abbey Road break new ground in the digital world.

VIRTUAL EQUIPMENT

Working with Israel-based software company Waves Audio, Abbey Road Studios has been recreating the sound of original Abbey Road equipment as plugins that can be used on audio-editing software. In much the same way as it is possible to use plugins on photo-editing programmes to stylise an image, audio can be similarly tweaked and enhanced.

Using the original schematics and technical drawings stored in Abbey Road's archive, Waves Audio is able to build virtual circuits that mimic the behaviour of real physical devices, such as resistors, capacitors, diodes, transistors, inductors and valves. Each component is recreated as a software element that behaves just as it would in the real world and the components are then pieced together as they were in the original Abbey Road equipment.

Test signals are put through both the original piece of kit at the studio and the virtual circuits so that they can be compared. Engineers then spend days fine tuning the digital version to ensure that it adds the same character and depth to audio signals as the original analogue circuits and valves would have done. At times, staff can find themselves listening to a snippet of drum just half a second long over and over again to see if they can pick up any difference or shift in the digital replica. It is a forensic process.

The list of recording equipment that has already been transformed into digital plugins is a re-creation of music history in itself. It includes 50-year-old tape machines such as the J37, which was specially developed by the studios' then owners EMI during the 1960s and 1970s, and was used during the recording of The Beatles' pioneering Sgt Pepper's Lonely Hearts Club Band album. There are recreations of Abbey Road's original reverb plates that were installed into the studios' echo chambers in 1957 and became popular on the pop albums of the 1960s and 1970s. A selection of mixing desks developed by Abbey Road's record engineering development department are also available, including the one used to create the psychedelic sounds of Pink Floyd's The Piper at the Gates of Dawn.

Another plugin allows users to filter their audio through software that recreates the unique frequency response of a rare set of three gold and silver embossed microphones that were custom-made for the Royal family during the 1920s and 1930s. One of them was used by King George VI during Britain's declaration of war against Germany.

There are virtual models of vinyl cutting, mastering and playback gear, passive equalizers and artificial double-tracking equipment, an effect that was invented for The Beatles. Each plugin has a graphical interface that replicates the look of the original machine, helping to give a taste of the experience of using it on their computer. It is allowing users to access equipment worth tens of thousands of pounds for less than £100.

The technique of building the digital replicas component by component also raised the possibility of resurrecting some long gone pieces of recording equipment. While the original physical devices have broken or disappeared, the schematics remain in Abbey Road's archives, and engineers have been experimenting with creating digital versions from these

The team at Abbey Road Studios has produced samples of three of the classical pianos that are kept in Studio One and Two at Abbey Road, including the uprights used by the Beatles and a Yamaha CFX1 Concert Grand Piano – an instrument that costs more than £120,000 new © Abbey Road Studios

drawings. Testing how they compare to the real thing could be a good deal trickier.

Fortunately, one piece of good luck may make the job of resurrecting a piece of equipment that has almost legendary status among audiophiles a great deal easier. In early 2017, a student radio station at the University of Southampton rang up to say that they had found an old tape machine that may have belonged to Abbey Road. When they read out the number printed in tiny type on the front, staff at Abbey Road were amazed. It was a BTR-3, a vintage tape machine custom-built by EMI at Abbey Road in the late 1940s, which became the main piece of recording equipment during the 1960s.

There were just three left in Abbey Road itself, but despite their best efforts no-one had been able to get them to work because of bad corrosion and damage in storage. By contrast, the newly discovered machine is in excellent condition, raising hopes that it may be possible to restore it to its former glory.

DIGITAL INSTRUMENTS

While the recreations of recording equipment at Abbey Road can give some flavour of the distinct sound that can be heard on albums recorded there, it is hard to beat actually playing in the studios. There is an emotional element to interacting with 50-year-old equipment with a weight of musical history behind it that is hard to replicate with software. The unique sound of the studios themselves, and the way sound reverberates between the walls, is also a key part of what artists hope to capture on a record at Abbey Road. To book one of the studios can cost thousands, but for those unable to stretch to that sort of budget, Abbey Road has developed another solution.

It has teamed up with German software company Native Instruments to create digital samples in its studios. Using original drum kits from the 1950s, 1960s, 1970s and 1980s, the studios were set up just as they would have been in each era and the sounds were captured. A musician played each instrument in as many ways as they could possibly imagine: hitting different parts of the snare, tapping rims, using different sticks or brushes, muffling the drum or holding the cymbal. It took three days to sample each drum kit by setting up 30 different vintage microphones from each era around Studios Two and Three. For each instrument, more than 10,000 individual sounds were captured before being chopped up in a process called scripting. These can then be mapped onto a MIDI controller so that the user can play the samples on an electric keyboard or drumpad.

Using multiple microphones to record the drum samples gives users the opportunity to reblend the balance from each microphone in the software as if they were sat behind the control desk. Each of the sampling sessions was organised to mimic the conditions from the era that they were trying to recreate, with drums from the 1980s recorded in the famous mirror-walled drumming room of Studio Two. The team was also able to source some vintage drum sets dating back to the 1920s from a collector who allowed them to sample the instruments, one of which was insured for more than £1 million, with some of the oldest equipment in the studios.

UNMIXING SOUND

Digital technology is not just giving old instruments and equipment a new lease of life, it is also resurrecting entire pieces of music. James Clarke, a technician at Abbey Road, tackled the seemingly impossible: unmixing a piece of music after it had been recorded. Throughout the history of recorded music, it has never been possible to successfully unravel the different components of a track if they were recorded together. To overcome this problem, sound engineers record the vocals and all the different instruments in a piece of music on separate channels, mixing them together in the control room.

For albums such as The Beatles' *Live at the Hollywood Bowl*, the problem is immediately apparent. On the original recording, the sound of the band is almost completely drowned out by the screaming of 10,000 fans. However, Clarke felt that it was a problem that modern digital technology could help with. He spent five years programming and tweaking software that could unravel all of the separate instruments and vocals from a track. The process involves modelling the music as spectrograms (a visual representation of the spectrum of frequencies) to help identify the component elements.

When he applied it to The Beatles' album, he was able to isolate each of the four's instruments and vocals from the messy cacophony, allowing an entirely new remastered version to be created. The new cleaned-up album was released in 2016 to coincide with Ron Howard's documentary about The Beatles' live tour *Eight Days a Week*.

THE FUTURE OF SOUND

Despite its history, Abbey Road is not just fixated on the past. It is also looking to the future. It has established an incubator, called Abbey Road Red, to support startups and academics who are developing innovative new products for the music industry.

One company to be supported by Red, California-based OSSIC, triggered interest in what many at Abbey Road hope could be a new direction for the studio. The company is developing headphones that can recreate a three-dimensional audio experience for listeners. Intrigued by the possibilities, Abbey Road has now begun working with researchers at the University of York to find ways of capturing sound in three dimensions. The idea of ambisonics was first developed in the 1970s by British engineer Michael Gerzon but failed to take off because of the expense of the equipment needed to listen to it.

With the development of virtual reality, there is now new impetus to make use of this technology to make the experience even more immersive. Hearing a sound behind or above you could act as an audio guide to help navigate a virtual world.

It has also raised new possibilities for the music world too; with the ability to throw sound at a listener from any direction, it could lead to new creative outlets for artists. Like many things at Abbey Road, it could help the studio build on its rich past. When the studios first opened, early engineers dreamed of capturing the full live experience for listeners, something that could finally be realised.

ABBEY ROAD RED

The Red audio technology incubator takes its name from Abbey Road's old research and development wing, the Record Engineering Development Department (REDD), which is where much of the equipment used in the studios' rich history was built. However, resurrecting such an expensive department was not an option in the modern business world. Instead, Abbey Road decided to look outside its own doors to find those who are pushing boundaries in the music industry and support them instead.

The scheme, which launched in 2015, offers startups a six-month mentoring partnership that gives companies access to Abbey Road's expertise, facilities and contacts in the music industry. Two new companies are signed biannually in exchange for a 2% stake in equity. For Abbey Road, the benefits extend far beyond any financial return by bringing new ideas and technical knowhow through its doors. The hope is that relationships formed during the incubation periods will lead the studios into new avenues for the business.

This drive to break new ground in the music industry has also seen startups that might be perceived as a potential threat to Abbey Road's central business being signed up to RED.

Cloudbounce is building music mastering software that uses artificial intelligence (AI) to polish records before they are released. It is something for which Abbey Road has built its own reputation, with a team of experts who master tracks for customers. AI could potentially provide a cheaper alternative to this service and so a rival to Abbey Road's business, but by working with Cloudbounce, it found that there were actually many ways that the services complement each other. AI could be used to give an initial quick mastering, while humans give the final polish to make it unique.

The other firm in the latest intake is Vochlea Music, a company that is creating a smart microphone that converts vocals into instrumentation. Using machine learning, the software recognises whatever instrument is being imitated vocally, such by humming or beat-boxing, and turns it into the corresponding guitar melody or drum beat for example. The company grew from a graduate project by George Philip Wright, a member of the Royal Academy of Engineering's Enterprise Hub, at the Royal College of Art and Imperial College London. He is using his Fellowship of the Hub to refine the technology into a product and build a new prototype of the microphone, but he hopes that it may also be adapted into other formats including a high end live performance tool for musicians.

Previous participants in RED include firms such as Titan Reality, which is developing three-dimensional sensing technology to turn gestures into music. It uses shapes and movements to enable fine control of software-driven instruments. Another called UberChord is developing an app to teach people how to play the guitar.

BIOGRAPHY

Mirek Stiles is Head of Audio Products at Abbey Road Studios. He joined the studios as assistant recording engineer in 1998 and has worked on projects such as *The Lord of the Rings Trilogy* and *The Beatles Anthology* and with musicians including Muse and Kanye West.

Jon Eades is Innovation Manager at Abbey Road Studios, heading up Abbey Road Red. He joined the studios in 2011.

CHIPS THAT CHANGED THE CLASSROOM

The team behind the Raspberry Pi computer had big ambitions when it developed and launched an inexpensive device the size of a credit card. After the computer won the Royal Academy of Engineering's MacRobert Award, Michael Kenward OBE spoke to Co-founder and CEO Dr Eben Upton CBE and Dr Andrew Herbert OBE FREng, a member of the award's judging panel, about how it sparked a revolution in low-cost computing that has spread far beyond the classroom.

It is the "sheer quality of the innovation" that set the Raspberry Pi apart from other candidates for this year's MacRobert Award, says Dr Dame Sue Ion FREng FRS, Chair of the MacRobert Award judging panel. "By blending old and new technology with innovative systems engineering and circuit board design, the team has created a computer that is cheap, robust, small and

A child makes pixel art using a Raspberry Pi and a Sense HAT add-on board, designed for experiments in space on Astro Pi. Volunteers from the Raspberry Pi community run events for thousands of people every year © Raspberry Pi Foundation versatile," she added. Something that set out to reverse the decline in computing education in the UK not only achieved that goal but also had an impact far beyond the expectations of the small Cambridge team who came up with the idea for an inexpensive single-board computer for schools and hobbyists. The team's work has also resulted in an intelligent, programmable controller that has found applications in many different industries.

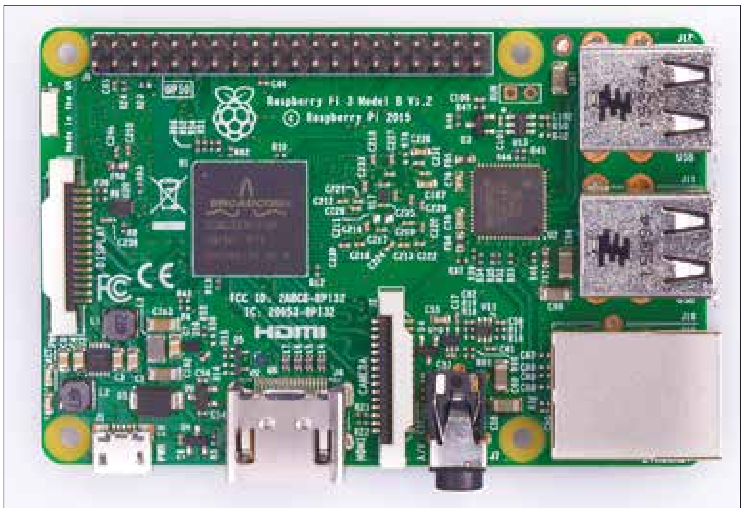
PLANTING THE SEEDS

Dr Eben Upton CBE set the ball rolling in 2006 while working as a Director of Studies at the University of Cambridge. He had noticed a decline in the programming abilities of students applying to study computer science at the university. At the same time, another Cambridge computer graduate, Dr David Braben OBE FREng, founder of Frontier Developments, had similar concerns about applicants for jobs at his computer gaming business. There was a growing view that this skills gap was due to the limited scope of computing teaching in schools. Students learned how to use word processors and spreadsheets, but had no opportunity to experience the thrill of writing software to do something creative with a computer.

Earlier generations of students had been able to experiment by programming devices such as the BBC Micro. Dr Braben certainly remembers that as being his introduction to computing ('An elite engineer', *Ingenia* 57), but these 'hobbyist computers' fell out of favour as schools moved over to the personal computers preferred by business users. With the memory of the BBC Micro as his inspiration, Dr Upton and his colleagues turned to his idea of an inexpensive single-board computer.

The advocates of the then unnamed initiative knew that they needed an organisation to develop the computer, to make it and to handle the all-important communications with their target audience, schools and teachers. Professor Jon Crowcroft FREng, one of the initiators of the new computer and a leading academic in the computer laboratory at the University of Cambridge, suggested the name Raspberry, in line with the tradition of naming computers after a fruit.

Six engineering enthusiasts set up the Raspberry Pi Foundation – the name Pi comes from the Python programming language, one of many that the device can work with – as a charitable company. The original trustees brought academics and business people on board, including Dr Braben, Pete Lomas, Co-founder and Director of Systems Engineering for Norcott Technologies, an electronic design consultancy,



The Raspberry Pi 3, the foundation's flagship product, is a bare circuit board that can connect to many different devices © Raspberry Pi Foundation

and Jack Lang, a Cambridge technology entrepreneur.

The trustees set out with goals to "get Raspberry Pis to kids" and provide secondary school pupils across the UK with access to the computers and the opportunity to learn to code. They also wanted to increase the public profile of learning to code so that the challenges and opportunities it presented became part of a national debate.

To achieve these ambitions, the team had to design a computer that would be inexpensive to make and sell. Fortunately, they could draw on plenty of local contacts. "I don't think we could have done Raspberry Pi anywhere other than Cambridge," Dr Upton said in a recent interview with the Centre for Computing History. There were plenty of academics and business people in the city who understood computing, and who also knew about how to finance and launch a new business.

COMPUTER ON A CHIP

By the time work started on what was to become the Raspberry Pi, Dr Upton had joined the Cambridge office of US company Broadcom as a chip architect. A small team of enthusiasts at Broadcom set to work, often in their spare time, to do "much of the practical heavy lifting," as he puts it.

Broadcom designs chipsets for mobile phones. Dr Upton and his colleagues realised that there was enough room for a conventional central processing unit (CPU) on the latest multimedia chip, and that by doing so they could turn it into the basis for a general-purpose

Launched officially at the end of February 2012, sales of the Pi 1 Model B hit 100,000 on the first day. By the end of the year, sales reached 800,000

computer. Rather than invent his own processor, Dr Upton chose a CPU from ARM, another Cambridge company designing silicon IP for mobile telephones.

The ARM processor allowed the new micro-computer to run its own variant of the Linux open-source operating system, Raspbian. This meant that the Raspberry Pi, known as the Pi in the community, started life with a full-function operating system that came with many programming languages and device drivers. The Pi team did not have to write a library of software before it brought the device to market: it could tap into the creativity and software of the large Linux community and many existing applications.

With the basic design ready, the team set itself challenging cost targets: it wanted to sell a fully capable personal computer for around £20 ($35). At the time, single-board computers cost around $100. The team also wanted its computer to connect to a wide range of devices and add-ons.

This connectivity also came into play with another important design feature: the Pi is a bare circuit board rather than a closed box that things are plugged into. Students are able build their own digital devices, which they can connect to anything that takes their fancy and that uses standard interface protocols for displays, network devices and anything that can work with the USB drivers written for Linux, such as printers. This design philosophy encourages the Pi's use as a programmable controller/interface, promoting a large and growing 'digital making' community of students, hobbyists and individuals who have created all manner of devices based on a variety of hardware, from robots and heart monitors to irrigation systems, catflaps and many examples of devices on the internet of things.

The Pi's flexibility has enormous implications. For example, Dr Andrew Herbert OBE FREng, a member of the MacRobert judging panel and previously Chairman of Microsoft Research for the Europe, Middle East and Africa region, sees digital making as a pathway into careers in engineering. "Almost every branch of engineering embeds computers one way or another," he says. "The Pi gets young engineers started on that journey. To me the attraction of digital making is that it turns 'electronics' into 'software'. Surround the Pi with a few simple interfacing chips, sensors and actuators, and write software to do all the control and data transfer – there is no need to learn how to design complicated electronics."

The designs for the Pi might have gone nowhere had it not been for what Dr Upton describes as an "accidental announcement", when the BBC's technology correspondent, Rory Cellan-Jones, mentioned the new computer in a blog in May 2011. "We got this enormous deluge of attention, and then we had to make it."

While Lomas worked on the important task of bringing all the components together onto a device about the size of a credit card, Dr Upton took to the telephone to persuade chip makers to sell at a price that would meet the Pi's £20 target. Hoping to order just 10,000 or so chips, he had limited bargaining power. He had no idea that the companies he talked to would end up selling chips by the million.

There was also a "frantic scramble", Dr Upton recalls, trying to find someone to make the devices. After failing to find a British maker, Raspberry Pi scraped together $250,000, mostly the trustees' own money, to pay a Chinese manufacturer to assemble the first 10,000 units.

In February 2012, the team invited people to sign up to buy the Raspberry Pi Model B. As Dr Braben recalls it, although there was no delivery date, when sales started, the rush to buy was so frenzied that it crashed the website and sold out "within seconds". Following this success, Raspberry Pi could rethink its production strategy and approached a Sony factory in Wales that did contract production for other businesses, bringing production of the Pi back to the UK.

Launched officially at the end of February 2012, sales of the Pi 1 Model B hit 100,000 on the first day. By the end of the year, sales reached 800,000. The team decided to set up Raspberry Pi Trading, with Dr Upton as CEO, to develop the third model, the B+. The new design gave developers even more access to the internals, further opening up the machine to new applications. Importantly, the team ensured that anything developed for the earlier machines would work on later models without any changes.

It was not long before the Pi team's achievements began to be recognised. In 2013, Dr Upton's achievements in bringing the Pi to the market won him a Royal Academy of

A teacher helps a child program a Raspberry Pi at one of the foundation's many Code Clubs. As part of its mission to put the power of digital making into the hands of people everywhere, Raspberry Pi provides free, high-quality learning resources and both face-to-face and online training for educators
© Raspberry PI Foundation

Engineering Silver Medal for outstanding commercial success.

CODING IN THE COMMUNITY

As the MacRobert citation says, the Raspberry Pi hardware has done much to put computing back into the hands of hobbyists, who were the early adopters of the Raspberry Pi, schools, and engineers in industry who want to develop inexpensive devices based on open standards. Pis make it easier for schools to teach students how to write code and introduce the skills that are invaluable in an increasingly digital society and, as the Pi started to come off the production line, it was the role of the Raspberry Pi Foundation educational charity to get that message out to schools.

Raspberry Pi Trading reinvests about a third of its profit in R&D, and the rest goes to the foundation. Grants and donations from other sources make up around half of the foundation's income. The turnover of Raspberry Pi Trading was around £16 million in 2016, yielding a profit of £8.9 million, which supports a wide range of community, outreach and learning activities. Several schemes support the original aim of bringing the excitement of programming to the classroom, such as Code Club, a network of teacher- and volunteer-run after-school programming clubs. There are now more than 10,000 Code Clubs running in 125 countries. "More than 140,000 kids have taken part in our clubs in places as diverse as the northernmost tip of Canada and the favelas of Rio de Janeiro," says Katherine Leadbetter, Code Club International Programme Coordinator. The activities of Code Club go beyond the original aim of reviving classroom interest in writing code. One club in Zambia, run by volunteer Mwiza Simbeye, started as a way of getting children off the streets of Lusaka and teaching them useful skills.

The foundation also helps computing teachers in their classroom activities. For example, Picademy runs free two-day residential training courses in computing and digital making for educators. There are also free online training courses for teachers and one-day workshops for teachers who want to start a Code Club.

The foundation's activities also support broader uses of the Pi. For example, around 250 teams from 15 countries are taking part in the current round of AstroPi competitions, which give young people the opportunity to design experiments and write programs that run on the International Space Station. Another project that uses Pi for scientific education is the Skycademy, in which trained educators work in teams with a high-altitude balloon pioneer to take photographs, and record and transmit atmospheric data back to the ground. In a joint

The MacRobert Award 2017 was presented to the Raspberry Pi team at the Royal Academy of Engineering's annual Awards Dinner in June (L–R): Dr Gordon Hollingworth, Director of Software Engineering; Dr Eben Upton CBE, CEO; Dom Cobley, Senior Principal Engineer; Liz Upton, Director of Communications; James Adams, COO; and Pete Lomas, Co-founder and trustee

programme with Oracle, 800 schools in 72 countries run Pi-based weather stations.

As Dr Herbert puts it, "through these outreach and educational activities, the foundation addresses the very need that first stimulated the invention of the Raspberry Pi, namely the desire to inspire young people to take an interest in computing and digital making, essential skills for the UK if it is to remain competitive in an increasingly digital world. It brings into schools the discipline and thrill of engineering problem solving and creative thinking."

The maker movement has also encouraged rapid growth in another market far beyond the founders' original ambitions. A third of the sales of the Pi are outside education, in industrial automation and consumer electronic devices. The Pi also finds its way into embedded controllers, data loggers and development platforms.

By the end of 2016, global sales of Pi computers exceeded 11 million, 80% of which were exported, making it the UK's best-selling computer. After just five years, the Raspberry Pi is a major player, not just in education and the personal computer market, but in a growing number of applications in countless areas of engineering.

BIOGRAPHIES

Dr Eben Upton CBE is Co-founder and CEO of Raspberry Pi Trading. He was responsible for the overall software and hardware architecture of the Raspberry Pi, and is a former trustee of the Raspberry Pi Foundation.

Dr Andrew Herbert OBE FREng is a member of the MacRobert Award judging panel. He was formerly Chairman of Microsoft Research EMEA and is Chair of Trustees for The National Museum of Computing

AWAY FROM THE CLASSROOM

The creators of the Raspberry Pi may not have set out to support manufacturing, research and other areas where an inexpensive, easily programmable, multi-purpose computer is invaluable, but that has certainly been a key part of Pi's success. "We like that people are building businesses on the back of the Raspberry Pi," says Dr Upton.

Along with schools and hobbyists, engineers in industry quickly started to experiment with the Pi. This sector now accounts for about a third of all sales, with applications in just about every area of engineering and research.

The Pi found favour in industry thanks to "ferocious attention to detail and in developing affordable production techniques to create a system that can be built cheaply yet to a very high quality," says Dr Herbert. This makes the Pi acceptable for use in practical engineering solutions in an industrial environment. One of Dr Upton's favourite applications is at a cucumber farm in Japan, which, thanks to the farmer's programmer son, uses a Pi to sort thorny cucumbers, saving the farmer eight to nine hours' manual work a day.

Researchers have also latched on to the Pi as a way of reducing the cost of equipment. A group of neuroscientists at the University of Tübingen, Germany, and University of Sussex has used 3D printed components and self-programmed electronics in a $100 imaging and microscope system that replaces commercial instruments that could cost tens or even hundreds of thousands of euros. Dubbed FlyPi, the system helps the researchers in their studies of roundworms, fruit flies, zebrafish larvae and other small animals.

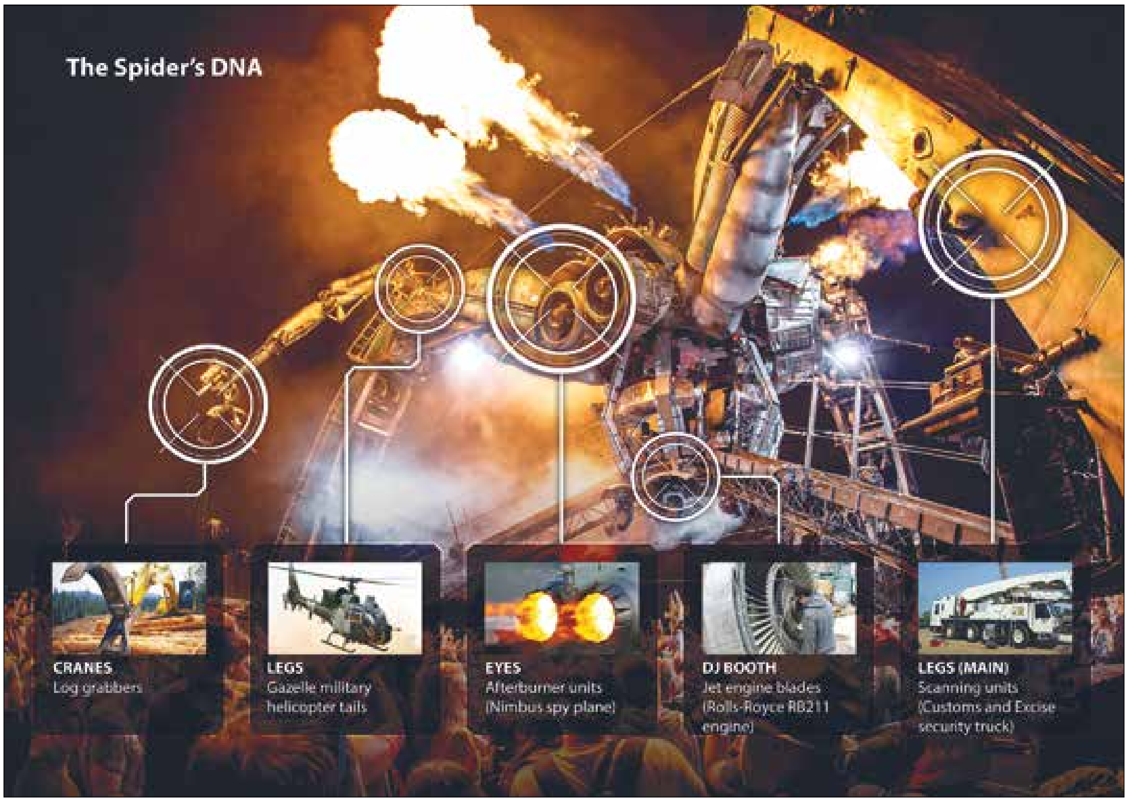
Lots of Pis: other ingenious uses of Pi

- The BrewPi Spark 3 can control the temperature of beer or wine fermentation with 0.1°C precision. It sends data to a Raspberry Pi to show a control panel with graphs in a browser.
- OpenSprinkler Pi, an open-source sprinkler/ irrigation extension board for Raspberry Pi, for garden and lawn watering, plant and flower irrigation, hydroponics, and other watering projects.
- Twike two-seat electric pedal cars, made in Germany, use a Raspberry Pi to collect and display information for the driver.
- An Indian team designed a Pi-based system to alert doctors when something abnormal happens on medical instruments that monitor electrocardiograms and other vital parameters.

The Arcadia Spider was designed to be a fully immersive stage, incorporating music, pyrotechnics, animatronics and acrobatic performances. It is made from recycled materials found in scrapyards and some of its performances are fueled by biodiesel rather than gas or petrol © Luke Taylor

FROM JUNK TO SPECTACLE

Synonymous with Glastonbury Festival, where it attracts thousands of partygoers each evening, the 15-metre-high Arcadia 'Spider' is an impressive, if unusual, example of engineering. Science writer Abigail Beall spoke to Arcadia Co-founders Bertie Cole and Pip Rush about how the Spider was created.



As the clock strikes midnight on each night of the Glastonbury music festival, those who make it to the Arcadia stage are treated to a spectacular show. In front of their eyes, a 15-metre-high, 50 tonne, mechanical, fire-breathing 'alien' spider hosts a DJ in its thorax, shooting out lasers and sparks while smaller metal spiders crawl overhead. In the middle of the dark field, flame-throwers, cannons and lasers operate in time with ground-shaking music, while sporadic blasts of heat produce shockwaves so powerful that they almost knock you over.

The Spider is not just an impressive spectacle; it is a unique example of engineering that is built almost completely from recycled material. The pair behind the creation, Pip Rush and Bertie Cole, have toured the world, impressing crowds with their machine ever since they created it in 2010. The Spider has been evolving with the; at each step along the way, the stage is shaped by the materials the pair can find locally in scrapyards.

THE LIFE OF THE SPIDER

A form of the Arcadia stage now so familiar to Glastonbury-goers first appeared at the festival in 2007. The company responsible for the stage, Arcadia Spectacular, began as a small group of engineers based in Bristol. Rush and Cole got their big break from Glastonbury's founder Michael Eavis CBE, who invited the company to set up a stage on his land.

Cole, the head engineer on the project, has worked in engineering since leaving school, when he went straight into a position working with tensile structures (a construction of elements carrying only tension and no compression or bending). Rush's background is in design: he had worked for years in his brother's Mutoid Waste Company, which specialised in designing structures out of materials found in scrapyards.

Rush and Cole combined their love for engineering and design with their enthusiasm for partying and dancing. Their original idea was for a 360-degree show that thousands could experience, with performers and animatronics moving over people's heads. Working with re-purposed materials generated unexpected challenges, some of which helped shape an evolving creative vision. Being unable to design a stage without first finding the materials to create it meant that the team had to work around the very specific shapes they managed to find in junkyards.

The first stage they designed was called the Afterburner, which was made in a cowshed in Dorset. Built from metal the pair could find in scrapyards around England, it looked like a combination of a rocket and a post-apocalyptic church with parts of aeroplane sticking out of it. The stage proved popular when it first appeared at Glastonbury; its sound systems were hooked up to a variety of DJs, and Arcadia was born.

JUNKYARDS

Arcadia has returned to every Glastonbury since. The familiar Spider stage debuted in 2010 after three scanning units from HM Customs and Excise security trucks were attached as legs to the original Afterburner stage. In 2012, spy plane engines were added to give it eyes. Cole explains that by reaching out into the audience, the legs provided a sense of immersion, while the eyes gave the stage character. Since then, lighting and special effects, including nine flame cannons and six lasers, have been used to further enhance the experience.

The Spider consists of a central body that includes the DJ booth and upper legs, which are made from helicopter tails. The three large lower legs are fixed to the body with a pivoting joint, designed so that the structure can easily be put together and taken apart. Once the three legs are connected, the team attaches a crane to each one with a pair of chains, which lifts the entire structure up evenly and allows the legs to pivot as it rises.

Because different ground surfaces provide varying levels of friction, the team does sometimes have to assist, using telescopic handlers to draw in the legs as the main body of the structure goes up. Once they are

After the legs are attached to the Spider's main body, a crane lifts them up so that they pivot and stabilise the structure (left). Ancillary components are attached using hydraulic platforms (right) © Giles Mayall

just above the design height, the three legs are connected with 20,000 kilograms of rated steel cables. As the tension is slowly let off the crane, the three legs push back against the cables. At this stage, the main structure is complete and the ancillary components are attached with the use of the crane, telescopic handlers or hydraulic platforms.

As the Spider is made mainly from materials found in scrapyards – at the 2017 festival over 90% of it was constructed from recycled material – putting the stage together not only requires engineering but also huge-scale improvisation.

When the team first developed the Spider, finding the three large 'crane' type components from the scanning machines immediately opened up the possibility of using them as legs and the other parts were designed around them. The legs were built to a far higher specification than was originally required. However, rather than downgrading them, all of the other components were manufactured to a matching size, allowing the structure's payload to carry 10 tonnes more than its design required.

A lot of the materials that were used to build the stage are ex-military. In its current form, the control booth in the Spider's abdomen is made of the turbine rotors from a TriStar jet engine. Cole and Rush trawl scrapyards to find the parts that they need and often find something unexpected that sparks an idea and takes their design in a completely new direction. The parts are often modelled using computer-aided software. This allows Cole and Rush to move the shapes around and see what is possible virtually, without having to transport huge machinery around.

IMMERSIVE SHOW

The Afterburner was designed to entertain about 3,000 people and looks the same from all angles. Unlike a traditional stage, it has a front and a back and a transparent 360-degree DJ booth so that everyone in the crowd can see the DJ. A central flaming spire extends from its centre and dancers stand around it on rings, performing simultaneously, while the crowd can dance on its 'tentacles' and trees made from old exhaust pipes blow out smoke.

The Spider stage has grown to host 50,000 people, each experiencing the same show whatever angle they watch it from and whether they are at the front or back of the crowd.

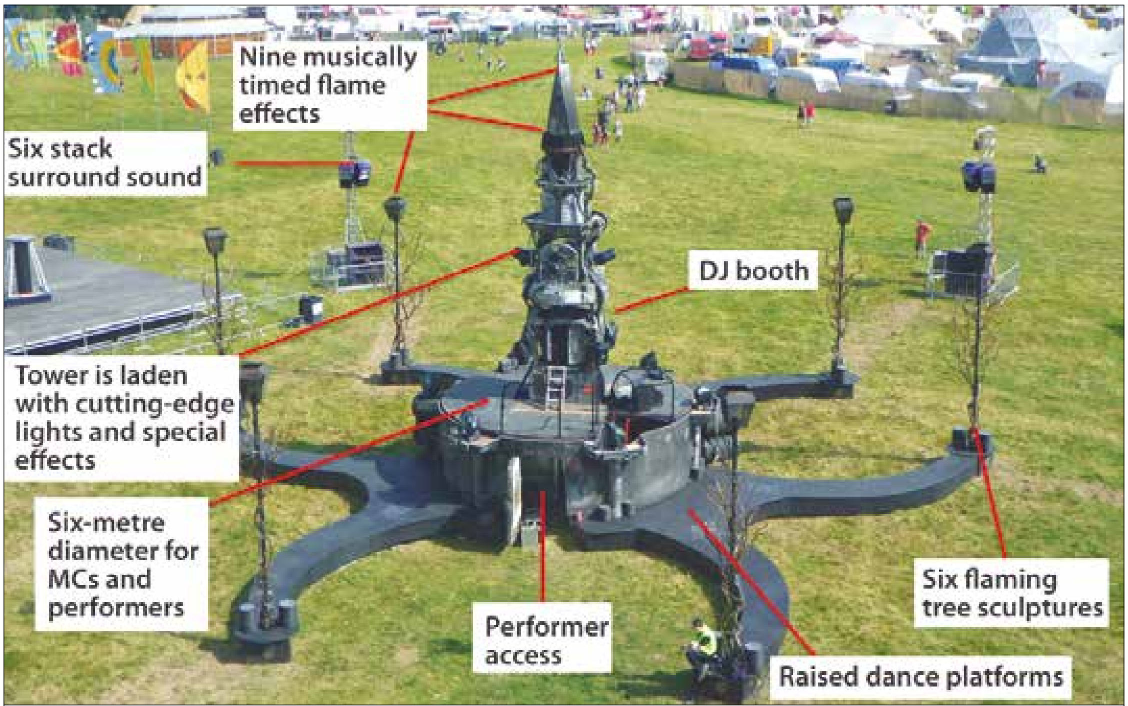
The Spider's performers are suspended from three hydraulic manipulator arms on the top of the structure. They are hoisted up and down, hang freely, and spin at high speed from the 'claws', made from log grabbers, at the end of the arms. Each of the three manipulator arms is controlled by an operator who is positioned at the 'shoulder' point of each set of limbs. They

SAFE YET SPECTACULAR

Safety is one of Arcadia's biggest challenges; while the show looks seamless to the audience, in the background there are rigging changes, people climbing over the stage, pyrotechnics, mechatronics and eruptions of 20-metre flames to consider. Once the parts to build the stage are found, the Arcadia team assesses the materials' strength so that the stage, and the performers within and around it, can operate as safely as possible.

Throughout the Spider's design, Cole and Rush sought help from structural engineers, analysing the steel the legs would be built from and using it as the basis to create the stable foundation upon which to build the rest of the structure. The Spider was constructed by a team of qualified welders and engineers in accordance with strict instructions from the structural advisors. Each time it is built, multiple commissioning and then pre-show checks are carried out and signed off before the performance begins and the public can go underneath. The team deploys multiple fail-safe protocols while the show is in progress, to ensure that performances flow smoothly and safely.

Unsurprisingly, there were no existing health and safety protocols for some aspects of the stage. The team works with regulators on the safety mechanisms built into the prototype and they together develop new protocols on a case-by-case basis.



The Afterburner stage has a number of features

control every arm movement in sync with the show's choreography. There is also a team of riggers on the structure who execute a bespoke series of sequences to coordinate human performers with the machine. Meanwhile, three smaller, lightweight spiders, each the size of a car and carrying two people, crawl above the crowd on zip wires with a realistically modelled mechanical simulation of spider movement.

OTHER STAGES

Arcadia has designed another stage called the Bug, a six-wheeled, amphibious stage built from a 1960s military vehicle, which is able to entertain up to 3,000 people, rolling on a self-contained structure. Two moulds from a nuclear submarine sonar cone are used at the back to form its wings, which open up to reveal a DJ, sound system and lights inside. The Bug featured in the closing ceremony for the London Paralympics in 2012.

Cole and Rush also have another company called the Lords of Lightning, which specialises in tesla coil shows. One involves two different tesla coils alternating between positive and negative charge, making lightning jump between the two. At Glastonbury's Arcadia show, two men stood on the tesla coils wearing chainmail suits and duelled with four million volts of electricity between them.

The show uses single tesla coils that are musically modulated, meaning that the frequency of the electrical signal can be used to play a certain piece of music, using the lightning as an instrument.

AROUND THE WORLD

The Afterburner tours the world putting on shows for about 4,000 people each time, and in the past year, the Spider has performed in the US, Australia, Taiwan, South Korea and Croatia. From the start of the design process, the team always aimed to take the stage overseas, so ensured that all of the individual parts could fit into a shipping container – everything needed to set up the stage and for the performance can fit into five shipping containers. On the ground, generic machinery, such as cranes and forklifts, is all that is needed to assemble and disassemble the Spider and speakers.

A slightly simpler show called Landing is performed in other countries, which requires about 50 people and takes around four days to set up. The Metamorphosis show at Glastonbury takes about five or six days and preparation includes the time required for performers to practise, and soundchecks with DJs to get the music, flames, and lasers working perfectly in sync. All of the elements have their own operating systems and are synced to the music using timecode controls.

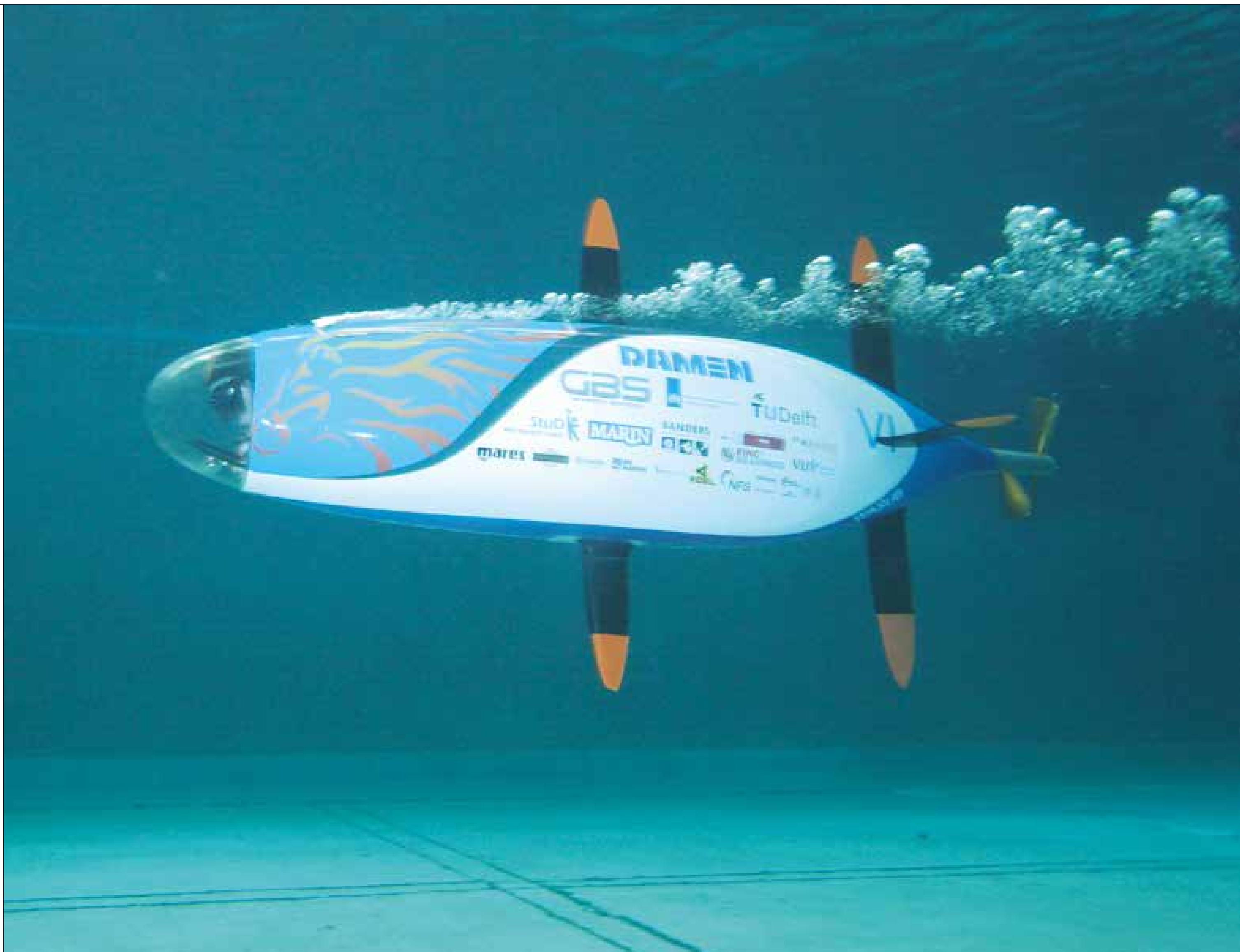
The large mechanical spider never fails to baffle all those who see it, from passing pedestrians to experienced engineers, and Cole says that explaining it to customs officials and health and safety officers has been an interesting process. When its flame throwers were tested ahead of a performance in Thailand, intrigued locals who had gone to see what was happening dropped to the floor and took cover.

With Glastonbury taking a fallow year in 2018, Arcadia has announced its own major event in the UK and the team is already developing new ideas and prototypes. Whatever comes next, from the Spider or the Arcadia team, it is certain that it will continue to intrigue and fascinate audiences in the UK and beyond.

BIOGRAPHIES

Bertie Cole is the Technical Director at Arcadia Spectacular. He had several years' experience making some of the world's largest tensile structures before co-founding Arcadia.

Pip Rush is the Creative Director at Arcadia Spectacular. He worked as a sculptor, creating installations and metallic landscapes from recycled materials before co-founding Arcadia.



The fastest submarine that took part in the 2016 European Submarine Race was WASUB 6 from Delft University of Technology in the Netherlands, which was propelled by contra-rotating propellers (above). The University of Auckland's Taniwha submarine was second fastest but scored better in its design report and reliability, winning the competition by a narrow margin

RACING HUMAN-POWERED SUBMARINES

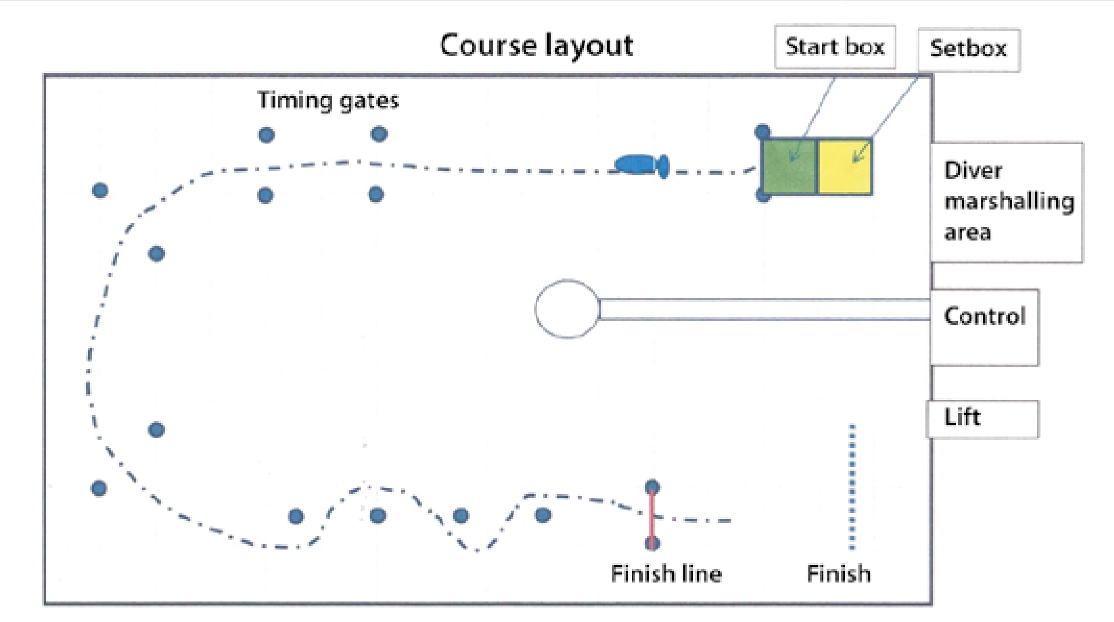
In 2012, a group of British engineers brought to the UK a competition that sees university students design, build and power their own submarines to race against each other. Sir Robert Hill KBE FREng, head of the judging panel, discusses the competition, while Iain Anderson describes the engineering behind his team's submarine that won the 2016 competition.

In the early 1990s, Florida Atlantic University conceived an event that could be described as the world's toughest university competition. It asked students to design, manufacture and then race submarines that were powered only by humans. For the purpose of the competition, the submarine would need to be a flooded underwater vehicle that fully enclosed the pilot and all propulsion and control mechanisms, operating entirely beneath the surface of the water, and powered by a propeller, jets or fins.

The first three competitions were held in the sea off a Florida beach, but since 1995, the International Submarine Race (ISR) has been held biennially in the David Taylor Model Basin at Carderock, Maryland, one of the largest ship model basins in the world, and has continued to attract an increasing number of international competitors. In 2015, 24 university teams took part and the event was won by a team from Delft University of Technology in the Netherlands, with a world record speed of 7.4 knots.

In recent years, the competition has spread beyond Florida and a European competition is now held in the UK. In 2011, a meeting between engineers from the Institute of Marine Engineering, Science and Technology, and QinetiQ led to the latter agreeing to hold the European competition (eISR) in its Ocean Basin ship model test tank, Europe's largest, in the Marine Park, Gosport.

The first eISR competitions were held in 2012, 2014 and 2016, with the next due to take place in July 2018. Teams from 14 universities around the world have taken part: four each from the USA and Canada, three from the UK and one each from Germany, the Netherlands and New Zealand. The University of Bath has taken part in all three races, while a team from the University of Plymouth competed in 2014 and teams from the University of Warwick raced in 2014 and 2016.

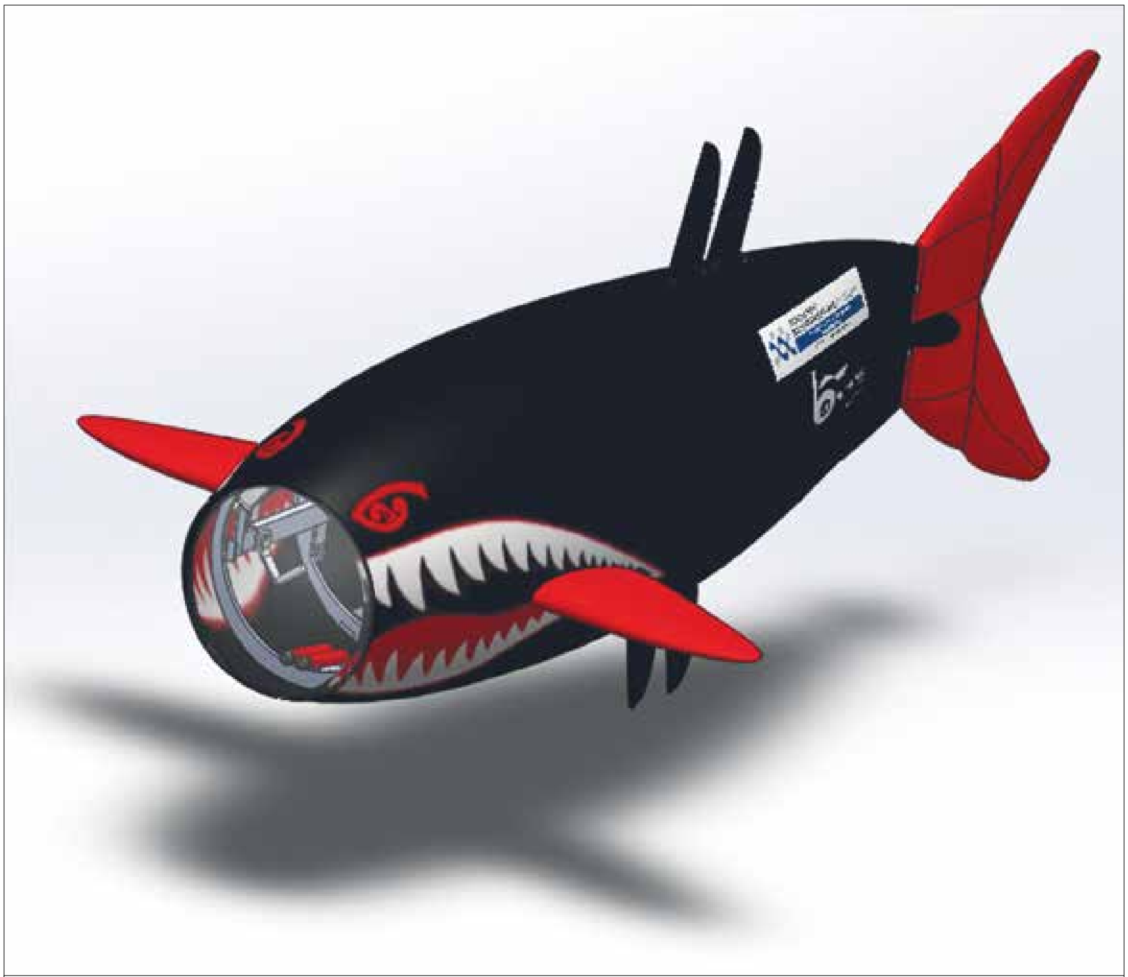


QinetiQ's Ocean Basin test facility is 120 metres by 60 metres, with a constant depth of 5.5 metres. Due to the size and shape of the tank, the course can be more challenging than the one used in the US competition. After a straight run to the 10-metre timing section, the course follows a long curve to port then returns to the starting end through a slalom section that is designed to test submarine manoeuvrability, creating a total course length of about 200 metres

DESIGNED TO WIN

The competition has been running for more than 20 years and still inspires a wide variety of designs. The only common design feature is the position and posture of the pilot, who is usually lying prone in the front of the hull, facing forward, with legs pedalling.

Most of the submarines entered into the competition are propeller driven and have a single pilot. However, a few two-person submarines have also been entered. Another type is the highly innovative non-propeller, biomimetic designs



The shape of the submarine's hull should have low drag and it is now common for the designers to use computational fluid dynamics to do this. A second requirement is that the nose of the hull should have enough transparency for the pilot to be able to see the course and the markers. A fully transparent nose cone can be seen on this CAD drawing of the original concept for Taniwha with dive planes at the front and fish-like rudder. Prior to the 2014 races, the rudder was modified to a more paddle-like rectangular shape to reduce drag

that take their inspiration from fish.

In 2016, the competition was won by a team from the University of Auckland's Biomimetics Laboratory. Unlike the majority of its propeller-driven rivals, Team Taniwha's submarine* was powered by fins, using two modified hands-free kayak pedals, with one set on top and another set underneath, that mimicked the New Zealand leatherjacket fish, which uses its dorsal and anal fins to swim either backwards or forwards.

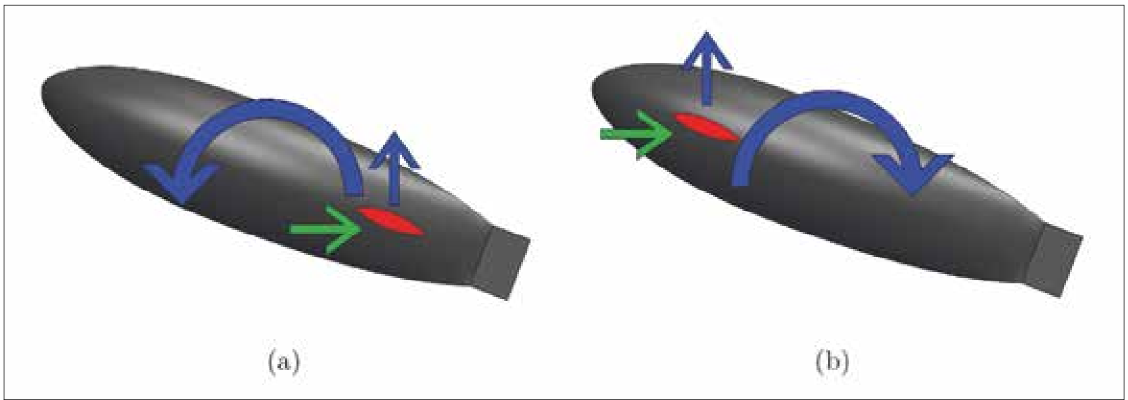
Having competed at the 2014 competition, the 2016 event was Team Taniwha's second trip to Gosport. The submarine entered in 2014 proved to be very unstable, crashing into the bottom or breaching the surface, and the vessel experienced frequent breakages in the string cables that linked the pilot's control levers to the rudder and dive planes.

This instability resulted from the dive planes being placed too far forward along the hull. If, for instance, the submarine began to lift its nose up a little, the forward-mounted dive planes introduced a lifting force that would make matters worse. A shark's pectoral fins are at the front, but they can bend their bodies up and down and side

THE CHALLENGE OF THE RACE

Competitors in the European International Submarine Race must successfully negotiate a winding course in the shortest time while fully dived, neither penetrating the surface nor hitting the bottom. To comply with the rules, student teams must design and make:

- a hull (or body) that completely encloses a sub-aqua diver, the pilot, and the propulsion and control mechanisms. This results in the pilots lying prone, face down and using their legs to provide the propulsion and hands to operate the controls. The submarine is not watertight, but fully flooded (open to outside water)
- a mechanism, propeller or fins that converts energy expended by the pilot into a means of propelling the submarine through the water
- a submarine that is neutrally buoyant with its pilot inside, so that when it is stopped underwater, it does not rise to the surface or sink
- a system so that the pilot can control the underwater depth and direction of the submarine when it is moving
- a transparent portion of the submarine's hull that allows the pilot to see forwards, side to side and down.

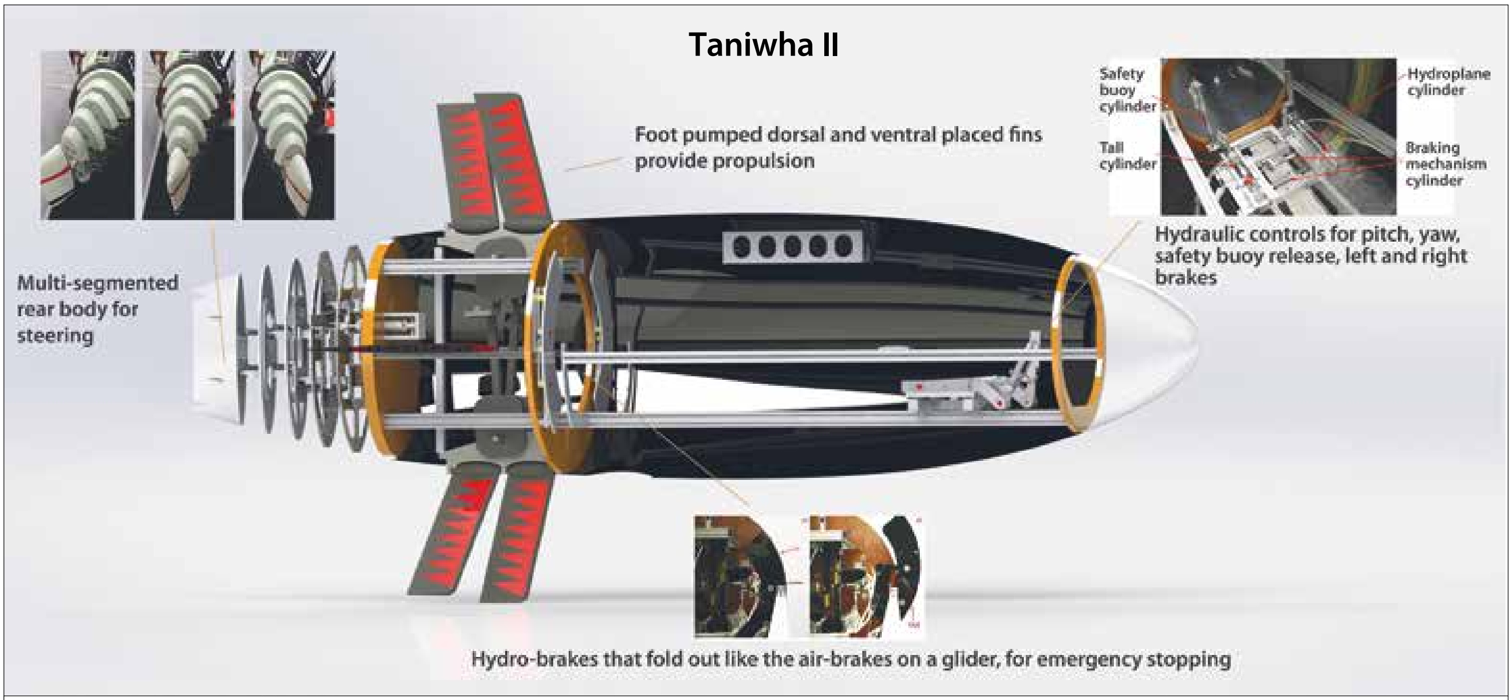


One of the central problems faced by the original Taniwha submarine was stability. The 2016 Taniwha dive planes were at the back for improved stability (a), unlike the 2014 unstable sub that had dive planes at the front (b)

to side, have quick reflexes and a superb sense of balance to control their swimming. Without such sensory systems evolved for underwater navigation, the Taniwha's pilot could not counteract a nose-up or nose-down orientation in time to stop the sub from continuing to rotate beyond the point of no return. To improve stability, the dive planes were moved towards the aft end of the submarine.

The team also replaced the string system of cables that was prone to breaking with hydraulic lines that used water-filled pneumatic (air) cylinders, which resulted in a more reliable control system. The effectiveness of both changes was demonstrated at the 13th International Submarine Race held in the USA in June 2015. Travelling along the 100-metre straight line course past a timing gate, the Taniwha completed 10 of 11 runs with a top speed of 3.65 knots, slightly less than two metres a second, the speed of a brisk walk.

In preparation for the UK-based race, the team decided to substantially improve Taniwha's ability to steer, taking another lesson from the leatherjacket fish, which uses its rear body and tail for propelling itself forward and steering. As well as being novel in the competition, steering by body bending proved to be extremely effective. The submarine's multi-segmented body could be made to bend around in a smooth curve, using one hydraulic cylinder. The bendy body segment was covered with a neoprene skin that could be unzipped and removed for inspection of the drive. This version also included hydraulic brakes that popped out from the sides of the hull.



Taniwha's features include a multi-segmented rear body for steering, foot-powered dorsal and ventral fins for propulsion, hydraulic controls and hydro-brakes that fold out

RACE WEEKS

The competition takes place over a two-week period. Submarines arrive at the start of preparation week, during which the marks of the course are laid, underwater timing cameras are positioned, safety nets are put in place and each team is allocated a workshop bay on the side of the Ocean Basin. Judges conduct a dry inspection, awarding marks for the quality of manufacture, and the teams' pilots and support divers have the opportunity to conduct tank familiarity dives. This is followed by wet inspections with QinetiQ's dive coordinator checking that teams can, among other things, release the emergency buoy and demonstrate correct starting procedure. QinetiQ also carries out risk assessment for the competition and provides the staff and workshop facilities to ensure that the event runs as smoothly as possible.

The outcome of the competition is not decided by speed alone, with marks awarded for the quality of the design report provided by each team, quality of manufacture, the standard of safety features and diver information, and reliability.

During the second week (race week), the competitors attempt the course, with judges plotting every submarine's track and recording any faults. The Taniwha increased in speed during the week, reaching a top speed of 4.7 knots on the Thursday afternoon after some small adjustments were made to the stiffness of the fins and the team taped over every hole in the body to improve hydrodynamic efficiency.

The slalom is made harder each day by offsetting alternate marks. As a finale, submarines that are still operational attempt two rounds of the course. Taniwha qualified for this event, but it meant that double the amount of air was required. A 10-litre bottle was substituted for the submarine's five-litre bottle, but the larger bottle interfered with the pilot's leg movement and hampered speed.

Underwater cameras are used to take measurements of speed through the 10-metre timing section as well as the overall time and scoring is based on the principle of 'fastest time with least faults'. At the end of each day's racing, submarines are ranked and marked accordingly. Despite the problems faced by the Taniwha team on the last day, it gained enough points overall to win and has its sights on the world record in 2018.

SAFETY

At the beginning of the race weeks, QinetiQ conducts a full safety briefing at the Ocean Basin before the dry and wet inspections take place. The teams' pilots and support divers conduct tank familiarity dives under QinetiQ supervision. For the wet inspections, the support divers hold the submarine underwater with the hatch open, the pilot gets onboard, and the hatch is shut and secured. The pilot must then demonstrate that the emergency buoy can be released and float to the surface when ordered. The team must demonstrate the correct starting procedure: at the underwater command, support divers swim clear, the pilot counts to five seconds and then starts pedalling. The purpose of the procedure is to avoid any risk of a support diver being struck by a rotating propeller.

Safety divers in an electric RIB (rigid-hulled inflatable boat) track every submarine around the course, ready to enter the water and release the pilot from a submarine if it is in trouble and aborting the run.

The pilot carries an independent air supply of no less than three litres, which is enough to enable the pilot to exit the submarine and swim to the surface. The primary air supply is carried on board the submarine and must have double the capacity required to complete a run.

BIOGRAPHIES

Sir Robert Hill KBE FREng is head of the eISR judging panel. He retired as a Vice Admiral in 1993, after spending 37 years as an engineer officer in the Royal Navy, serving in surface ships and submarines and becoming Chief Naval Engineer Officer and Director General Submarines in the MoD.

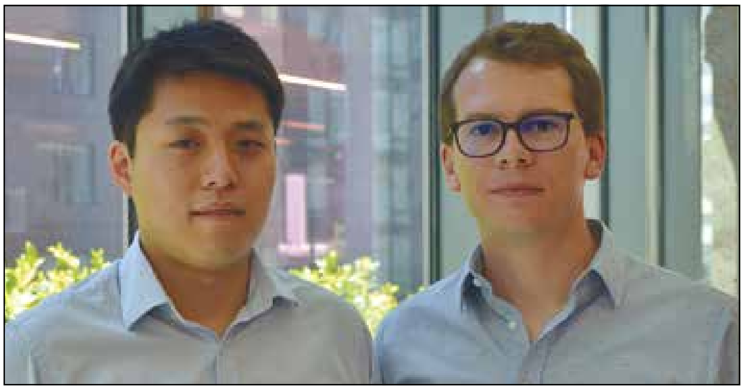
Iain Anderson is an Associate Professor at the University of Auckland. He leads the Biomimetics Laboratory of the Auckland Bioengineering Institute and manages team Taniwha. The team included Gerrit Barker (diver), Stefan Jäger (diver), Ben Pocock (lead engineer and diver), Chris Walker (team captain and pilot), and Sanjay Surendran (lead diver).

To find out more about the competition, please visit **www.subrace.eu**

*To see the submarine in action, please visit www.youtube.com/watch?v=BKBIOe0t_Mc

SILVER MEDALLISTS

The Royal Academy of Engineering Silver Medal was established in 1994 to recognise an outstanding personal contribution to British engineering that has resulted in successful market exploitation.



ROB BISHOP AND DR ZEHAN WANG

In 2014, Rob Bishop and Dr Zehan Wang founded Magic Pony Technology, a research-led technology company that developed an approach for using machine learning to enable more efficient delivery of images and videos on mobile devices. The technology enables high-quality video streaming at reduced bandwidth by improving the visual quality of highly compressed video content using machine-learning models.

Rob studied electronic engineering at Imperial College London, and was the first engineering employee at the Raspberry Pi Foundation, while Zehan completed a PhD in visual information processing for medical image analysis at Imperial College London's Department of Computing. The pair met at Entrepreneur First, an investment programme for enterprising engineers and technologists, where together they spotted the opportunity to use the newly available computational capacity of mobile devices to improve the quality of compressed media content.

Their technology uses deep learning algorithms that predict what information has been lost in a compressed video and can then reproduce it to reconstruct high-quality footage, even when the media has been transmitted at a low bit rate. The machine-learning models used in the technology have been trained using thousands of pairs of test images, each with a high-quality and corrupt version of the same image. The software then learns how to recreate the image from the corrupt version, which can then be used in the real world when only the corrupt version is available.

Magic Pony Technology was acquired by Twitter in 2016, and its engineers have now joined Twitter's Cortex division of machine-learning researchers, with the potential to apply their expertise to future problems in delivering high-quality media to increasing numbers of people.

The technology developed by Rob Bishop and Dr Zehan Wang uses machine learning to enable high-quality video streaming through Twitter on mobile devices

Billy Boyle invented a programmable 'breathalyser' for disease that he hopes will save 100,000 lives and $1.5 billion in healthcare costs

BILLY BOYLE

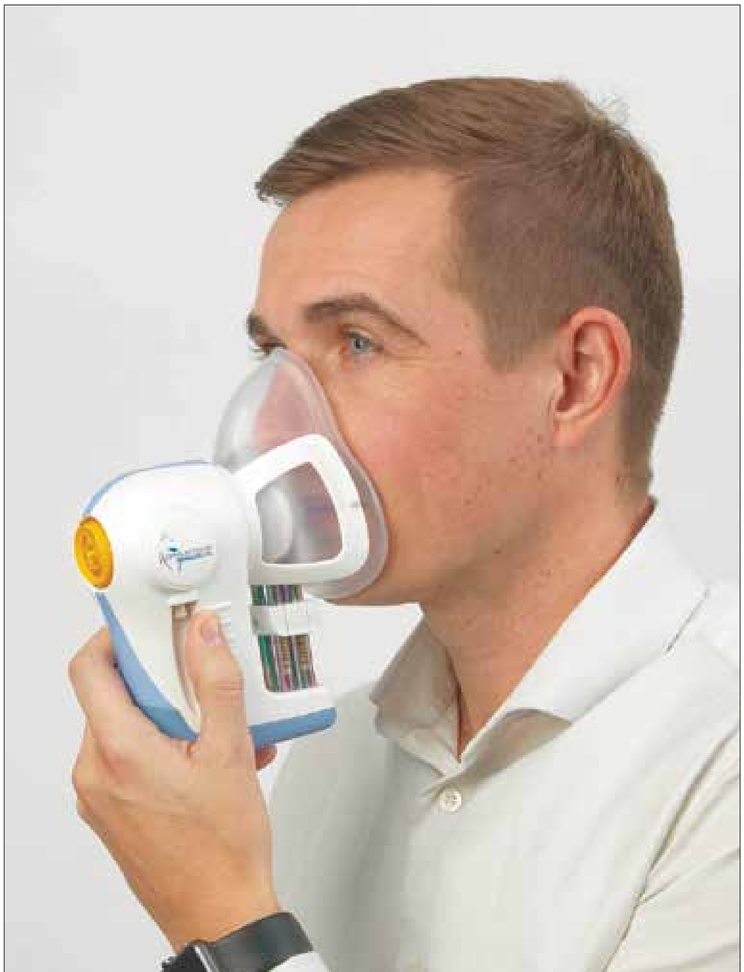
Billy Boyle is CEO of the Cambridge-based company Owlstone Medical. He invented a programmable 'breathalyser' for disease that he hopes will save 100,000 lives and $1.5 billion in healthcare costs.

Billy initially developed the chemical sensor for military applications when working as a researcher at the University of Cambridge. With two colleagues, he entered a student business plan competition where they were runners-up, but managed to secure $2 million of investment to start Owlstone in the months following the competition. Owlstone Medical span out of its parent company in 2016. It now has 88 employees and has raised $23.5 million to develop its healthcare technology.

The Breath Biopsy platform enables breath to be collected and analysed using a chemical sensor on a silicon chip, based on a technique called field asymmetric ion mobility spectrometry (FAIMS). Human breath contains thousands of chemicals, some of which are tell-tale markers of disease that the microchip chemical sensor can detect. Billy has demonstrated the diagnostic power of FAIMS across a range of infectious and inflammatory diseases, as well as different types of cancer.

In 2015, he led a project that resulted in a 3,000 patient study, aiming to develop a cancer breathalyser for early stage lung cancer detection, supported by a £1.1 million NHS contract. Owlstone Medical is currently running breath-based clinical trials for early detection of lung and colorectal cancer, two of the most common and difficult to treat cancers.

The Breath Biopsy platform has the potential to revolutionise early detection and precision medicine where treatment can be tailored to the individual patient.



Billy Boyle's Breath Biopsy technology analyses chemicals contained in human breath in order to help diagnose a number of diseases

Since 2013, the OrganOx metra has been used in more than 240 transplants in seven countries

PROFESSOR CONSTANTIN COUSSIOS

As co-founder of OrganOx ('Organ transplant breakthrough', Ingenia 66), Professor Constantin Coussios has led all engineering aspects of the development of the world's first normothermic liver perfusion device. The OrganOx is capable of storing livers at normal body temperature for extended periods of time to achieve improved organ preservation and utilisation prior to transplantation.

In 2013, the OrganOx metra was used in the world's first transplant of a human liver preserved at body temperature, known as normothermic preservation. It has since been used in more than 240 transplants in seven countries and has demonstrated better organ utilisation and improved transplant outcomes compared to conventional cold storage. It can store a functioning liver outside the body for up to 24 hours, improving transplantation logistics for medical practitioners and patients. The system also monitors the organ while preserving it, providing reassurance that organs, especially those that are higher risk, are functioning properly before being transplanted.

OrganOx now employs some 20 people, and the OrganOx metra is in use across the NHS, where it was instrumental in more than 10% of NHS liver transplants in 2016. It is also being used in hospitals in Belgium, France, Germany, Spain and Canada, and is undergoing a major trial to enable its introduction into the USA.

The next stage for OrganOx is to extend its method to

The OrganOx metra can store a functioning liver at body temperature for 24 hours, allowing longer time for a suitable patient to be matched

other organs, such as kidneys. The team is aiming for its first normothermic preservation kidney transplant next year. Professor Coussios is also working on improving other medical treatments, such as using tiny bubbles to help pump cancer drugs deeper into tumours to maximise the drug's effectiveness and how this technology could be used to deliver other drugs such as vaccines and gene therapies.

Deepmind has made pioneering breakthroughs in artificial intelligence (AI), and focuses on developing AI that learns to solve problems through trial and error

DR DAVID SILVER

Dr David Silver is Principal Research Scientist at DeepMind, where he leads the reinforcement learning research group and is the lead researcher on AlphaGo, the first computer program to be able to play the ancient Chinese game of Go at a professional level. Deepmind has made pioneering breakthroughs in artificial intelligence (AI), and focuses on developing AI that learns to solve problems through trial and error.

Dr Silver joined DeepMind in 2013, and began work on the Deep Q-network algorithm (DQN). He then led a team of over 20 scientists and engineers to develop AlphaGo, which famously defeated the reigning Go world champion at the time, Lee Sedol, in March 2016 in an event watched by 200 million viewers.

The reinforcement learning research group is now focusing on making AlphaGo-like algorithms that are more widely applicable, enabling them to develop algorithms that could one day help scientists tackle complex problems, such as finding new cures for diseases, dramatically reducing energy consumption, or inventing revolutionary new materials.

Dr Silver's research on DQN, a deep reinforcement learning agent, managed to reach human level in a selection of over 50 Atari games, directly from raw pixel inputs. This was the first demonstration of an artificially intelligent agent that could learn from scratch to achieve high performance across a wide variety of challenging games.

DeepMind's teams are focused on advancing its mission to solve intelligence and pushing the boundaries of AI by developing programs that can learn to solve any complex problem without needing to be taught how.

World number one Go player Ke Jie competes against AlphaGo at the Future of Go Summit in Wuzhen, China © Google

NATURAL BORN CODE WRITER

After spending time in Silicon Valley, Suranga Chandratillake FREng has been a partner at Balderton, a finance firm that invest in startups, since 2014 © Ian Buswell

A childhood introduction to writing software for a BBC Micro set Suranga Chandratillake FREng on a path that led to Silicon Valley, and a hugely successful software startup before he returned to the UK and began backing the next generation of young entrepreneurs. He talked to Michael Kenward OBE about his passion for engineering and technology.

Success in starting Blinkx, a software business turned media company, has garnered Suranga Chandratillake FREng superstar status in the world of IT, not to mention a Royal Academy of Engineering Silver Medal. But the coverage fails to mention that he was the first web editor of the University of Cambridge's student newspaper, *Varsity*. Chandratillake was studying computer science, so the *Varsity* team asked him to sort out its fledgling web presence. This was an early introduction to a new technology that was about to disrupt the media and the wider world, and would pave the way for businesses such as Blinkx, itself a media revolutionary.

THE DIGITAL LIFE

Chandratillake is a part of what has come to be known as the 'digital native' generation, someone who has always had computers in their lives. In his case, it started at around the age of eight when his father, an academic scientist at the University of Manchester, brought home a BBC Micro computer. Like many youngsters, Chandratillake wanted to play computer games. "I asked my dad if he would buy me a game," he says. OK, said his dad, but first you have to learn how to program the computer. Chandratillake got side-tracked into writing software, which he was fascinated by. He was, he says, "fluent in BASIC [programming language] in less than two weeks. I never got a game because I didn't need one after I had learned how to program. It was much more fun to write programs for myself. I enjoyed computers and software, writing code pretty obsessively really from the age of eight or nine. This meant that when I was thinking about university I thought that computer science looked really interesting." He chose to study the subject at the University of Cambridge partly because he found it relatively easy, leaving time to pursue other interests, such as economics and politics.

When it came to finding a job after graduation, Chandratillake learned another lesson in economics. This was the time of the dotcom meltdown, and his first job ended after just a few months. Fortunately, one Cambridge company, Autonomy, was still hiring and Chandratillake joined it as the lead R&D engineer on Autonomy's core data analysis engine. It was not long before the company sent Chandratillake to California as Chief Technology Officer to set up an office in Silicon Valley.

Autonomy was in the business of managing huge amounts of data with its enterprise customers, but the Bay Area enthusiasm for consumer technology rubbed off on Chandratillake. He found himself in a world of quick moving startups, with investors rushing to Silicon Valley to back the businesses that they hoped would one day be worth billions of dollars. The chance to enter the realm of consumer tech came when Chandratillake started an internal project in Autonomy. Partly to deal with the floods of emails that he faced in his job, Chandratillake set up a small team to develop software that would index and find information at a desktop level.

The move out of enterprise and on to the desktop, with what was to become the Blinkx software, was a big shift for Autonomy. "The Blinkx product and customer base were completely different from Autonomy," he explains. This prompted Autonomy to set up Blinkx as a standalone business in 2005, with Chandratillake as CEO. Hoping to turn it into one of those billion dollar businesses, it followed the traditional funding model, with additional help from Autonomy, to get the business started.

As a small standalone venture, Blinkx could change direction quickly. Within a year, the company switched focus from finding emails and text files to searching the hundreds of thousands of hours of video and audio files uploaded to the internet. In effect, Blinkx became an internet search engine for audio and video content, evoking frenzied media comparisons with Google. That was just the first change of direction. In the end, Blinkx decided to exploit its ability to search multimedia files to sell advertising. Blinkx became a media company, and Chandratillake found himself again using the web for media purposes. As he says, changing direction is a standard pattern in Silicon Valley with Oracle, Microsoft and Facebook reinventing themselves over the years. "All great tech companies do."

This change of direction was an important lesson that he continues to draw on and it added to Chandratillake's entrepreneurial experience, which began while he was working at Autonomy with Mike Lynch, the company's CEO. "I was lucky to have joined Autonomy, which was an incredibly entrepreneurial place," he explains.

Blinkx also taught Chandratillake how to manage, and raise money to fund, a rapidly growing business. In 2007, that growth led to a float on the London Stock Exchange, where in time Blinkx joined the small club of IT startups in the UK worth over a billion dollars.

MAKING CHANGES

Chandratillake's time as CEO of Blinkx also convinced him that he preferred engineering and technology to running a large business. He also wanted to spend more time with his family and his young son, and missed being around for important meetings on the future of the business's technology and new products. As he said after the event "instead of thinking about the future of video online, I was worrying about legal, HR and investor issues."

In 2012, Chandratillake moved aside from the CEO's job to become Chief Strategy Officer (CSO). He made the shift, he said, "so that I could really focus on what I'm most passionate about at Blinkx – innovation, ideas and implementation of what I believe to be the future of video online". Chandratillake admits that he had to convince people that the choice to change jobs was his. As he explained after the move, "people assume no one would voluntarily step back from running their own company." He stayed on as CSO for a few more years, dispelling any lingering doubts about his reasons for moving offices.

His family also came into play when Chandratillake started to think about his next move. He and his wife, who works in the biotech sector, had a tentative plan to return to Europe with their two children. They had also spent time in the UK after Chandratillake finally stepped down from Blinkx. He sensed that things were changing in Europe, especially in the UK. If anything, he says, the stakes are higher here. "In Silicon Valley it almost doesn't matter if the company you're in succeeds or not, because there is another one five minutes later, whereas here it felt more important. That drove us back as well."

Chandratillake did not rush into a new job. After the Blinkx float, he spent a couple of years trying to work out what he wanted to do. In the end, he opted for another of his earlier passions: finance. "Finance is fascinating to me," he says. "I had done a fair amount of personal investing, so I had a sense of what that was like. I knew that I enjoyed it and the way that it gave me exposure to early-stage companies." He liked the idea of being able to work with a spread of companies and being able to share some of the things that he had learnt. He wanted to help fledgling CEOs to navigate the obstacles that he had experienced in his business.

TECH INVESTOR

Chandratillake decided to become an investor with a focus on technology. He made the move after he got to know the team at Balderton, a relatively small finance firm that specialises in investing in startups, often in technology. Chandratillake is one of five partners who own Balderton. The firm, set up in 2000, has funds totalling $2.3 billion and is involved in what is known in the business as series-A funding. This typically means investing between $5 and $6 million dollars to back teams of 30 to 40 people. As well as providing finance, the firm also draws on the experiences of its own team to guide founders through what can be difficult times. Chandratillake may not have had a business fail under him, sometimes seen as a badge of honour, but he says that it was not always a roaring a success. "At Blinkx, we had a lot of products and businesses that didn't work. At Balderton, we put a premium on having a team that has had entrepreneurial experience because the entrepreneurs we back are going to go through some really rough times."

As the resident engineer, Chandratillake believes that it is also important to have a team that includes people who understand technology. This knowledge of technology, he says, sets Balderton apart from other funds, many of which, as he puts it, have always been investors and can struggle with the technology.

Chandratillake is careful when it comes to deciding what constitutes 'technology', feeling that a 'tech' label cannot just be put on a business idea just because there is a computer somewhere in the system. For example, he explains: "I have looked at companies in the wine business, where you just go to a website, search for what wine you would like to buy, buy it, and they have got a warehouse and send it to you. There's nothing wrong with the business but I don't see how that's a technology business." However, Balderton has backed a 'wine business' that really does depend on technology. Vivino uses the processing power and connectivity of smartphones to bring together customers and wine suppliers. The smartphone app recognises wine labels and wine lists, for example in a restaurant, and matches the image using visual intelligence. It can tap into the views of fellow drinkers as well as wine suppliers and can track down suppliers of a wine that takes your fancy. "Before, you would have to roll out machines everywhere, and have a website that people have to come to," says Chandratillake. "Now you don't have to do any of that; you can put everything onto a mobile phone, which was impossible five years ago."

Vivino is one of a growing portfolio of tech investments that Chandratillake has a hand in. On the engineering front, he

At Balderton, Chandratillake is keen to mentor and support the young entrepreneurs whose businesses the firm is investing in © Rachel Swindenbank

highlights several in additive manufacturing. For example, Sketchfab allows people to share 3D designs over the internet: "A bit like how YouTube lets you upload a video and share it anywhere you want, you can upload your 3D design and share it anywhere you want." Another additive manufacturing business is 3D Hubs: "You can go on to its site, upload any 3D designs you have, and 3D Hubs will find you a local 3D printer who can print it for you."

It takes time to find interesting investment opportunities such as these. Chandratillake estimates that the firm sees around 4,000 ideas from entrepreneurs from across Europe each year. They can be direct approaches, a business that someone in the firm finds interesting, or occasional tips from 'angels' who invest in the early stages of a company. Of these leads, each partner may look at as many as 200 business ideas. If Chandratillake likes an idea, and if he can persuade the business to take his money, a deal can happen in as little as two weeks.

THINKING LIKE AN ENGINEER

Chandratillake sees his role as being more than simply finding and funding good ideas. He is there to help the founders to realise their ambitions. This is where the knowledge of what it takes to develop a business and its technology, and his background in starting a successful business and navigating it through sticky times, comes into play.

Chandratillake provides this mentoring beyond Balderton's own portfolio. As a member of the Enterprise Committee at the Royal Academy of Engineering, he can often be found in the recently opened Enterprise Hub, rubbing shoulders with the young engineers who have grand plans for new businesses. "The Hub has got billions of dollars' worth of investors signed up as supporters. It has a large number of mentors, both from the Fellowship and from outside." He has also been involved in judging competitions at the Academy for startup businesses. "All of these things are helping engineers who want to build businesses."

Chandratillake believes passionately in the power of the engineering way of thinking. "If you follow an engineering discipline, it gives you a way of thinking about the world and of modelling and structuring your thoughts." His view is that an engineering education, and the mathematical skills it involves, sets you up to do just about all that it takes to start and grow a business. For example, he insists, "anyone who has done an engineering degree can do the maths involved in marketing".

Chandratillake dismisses the mindset that engineers cannot take a business through to success. "There is a very strong notion in the UK that starters and founders are almost never the right person to build a company. I really hate that idea," which he dubs the "boffin fallacy". There is no equivalent word for the word boffin in America, he adds, "but every Brit knows what a boffin is. It is this slightly incompetent, doesn't understand the real world, scruffy character, who understands some minute bit of technology." In reality, he insists, technology moves so rapidly, and is such a dynamic market, that the 'non-boffin' skills an entrepreneur needs to learn are trivial compared to being able to understand the technology at the heart of what they are building. Just look at the big tech successes, he continues. "Facebook has reinvented itself at least three times because the guy at the heart of it all is a technical guy."

Chandratillake now wants to convince young engineers that they can succeed as innovators and entrepreneurs. Fortunately, he sees signs of progress in the UK. A lot has changed since he left for Silicon Valley

In his role as a mentor in the Royal Academy of Engineering's Enterprise Hub, Chandratillake is heavily involved in the Academy's support of startup businesses, judging competitions and giving talks to aspiring engineering and technology entrepreneurs

at the beginning of the century. When he completed his degree it was, he says, rare for graduates to think about starting a business: they were split roughly evenly between staying in academia, getting a job with 'big IT' or going into the City. "Now it is totally different," he adds. "Last year the single biggest recruiter out of the University of Cambridge's computer lab was Entrepreneur First." This accelerator, he explains, lets engineers and computer scientists try being an entrepreneur for six months before they get their first job. "The fact that that has come out of nowhere in about 15 to 20 years has been remarkable."

There is now more practical help for young entrepreneurs, he says. "If you started a company 20 years ago in Britain, there were not that many people around who could actually help you think about how to grow it into a billion-dollar enterprise. I think that is getting better all the time, and that is one of the reasons why I moved back."

However, there are still barriers to innovation in the UK. For a start, he says, we need to do a better job of convincing engineers that they can do it themselves, and that they can actually build companies if they want to do that. They should then be supported in their ability to do that.

Another obstacle can be finance for new businesses. There may be plenty of angels in the UK who can provide seed funds to help engineers start businesses, but it can be harder to raise the seven-figure sums that Balderton and a handful of other finance houses can put into a business. In part, he says, this is because local angels, for example in places like Cambridge, one of the UK's IT hotspots, struggle to get venture capitalists excited enough to nurture startups through to the next stage. It works better in Silicon Valley, he adds. "There are people who invest really early, as little as $5,000 to get something off the ground, but then they are very good at handing that on."

How will Chandratillake judge his success in this new phase of his career? As an investor, he naturally wants to make money, but that is only a part of the plan. He wants to make a real difference. This is one reason why he is enthusiastic about his work with the Academy and why he is keen to back businesses that can float on the stock exchange. "We love things that go public because that typically means that they are going to stick around for longer and make more impact on society in general, which is definitely part of what we like to see." This is partly why he returned to the UK. "I look at Europe and I think that there are going to be a number of really tough challenges economically over the next 20 or 30 years. Britain will not be shielded from that. One of the things that I think can help us is getting good technology, and exploiting the fact that we are already very good at technology."

BIOGRAPHY

Michael Kenward OBE has been a freelance writer since 1990 and is a member of the *Ingenia* Editorial Board. He is Editor-at-Large of *Science|Business*.

CAREER TIMELINE AND DISTINCTIONS

Born, **1977**. Studied Computer Science at the University of Cambridge, **1997–2000**. Lead R&D engineer, Autonomy, **2001**. Chief Technology Officer, Autonomy, **2003–2005**. Founder and CEO, Blinkx, **2005–2012**. Young Global Leader, World Economic Forum, **2009–present**. Chief Strategy Officer, Blinkx, **2012–2014**. Awarded Royal Academy of Engineering Silver Medal, **2012**. Fellow of the Royal Academy of Engineering, **2013**. Royal Academy of Engineering Enterprise Committee, **2013–2017**. General Partner, Balderton Capital, **2014–present**. Board member, Vivino, **2014–present**. Board member, Magic Pony Technology, **2015–present**.

INNOVATION WATCH

SAVING SIGHT IN DEVELOPING COUNTRIES

Arclight, a low-cost, solar-powered diagnostic eye-care tool, is being used by thousands of health workers in developing countries to identify preventable sight loss conditions.

The Arclight is an affordable, solar-powered ophthalmoscope, a diagnostic tool that is used by health workers to view the interior of the eye and detect early signs of blindness. The device was developed over five years by researchers at the University of St Andrews. Its compact size and small price tag, coupled with its ability to harness solar power, mean that it can be useful to clinicians working in low-income and remote locations.

Ophthalmoscopes are essential for diagnosing nearly all eye abnormalities, enabling skilled users to see the front and back of the eye and revealing conditions such as cataract, glaucoma and trachoma, which can all cause blindness. The instruments can be expensive, so availability can sometimes be limited. Around 220 million people around the world are visually impaired or blind, 80% of whose blindness would have been avoidable if treated, according to the World Health Organization.

Optometrist William J Williams, who is Director of Arclight Medical and an Honorary Research Fellow at the University of St Andrews, set out 10 years ago to produce a portable, intuitive and affordable diagnostic tool. He came up with the idea for the Arclight by stripping unnecessary features from a traditional direct ophthalmoscope.

Supported by a team at the university and awarded £100,000 from The Fred Hollows Foundation, his breakthrough was swapping the traditional filament bulb, which can be difficult to replace in remote communities, for a cool, low-energy LED. The design eliminates the need for the mirror and optics inside conventional ophthalmoscopes, replacing them with an LED facing the patient. This is closely aligned with a sight-hole that produces near coaxial light paths to give the user a dust-free view of the eye's interior. Clinicians can also use a slider on the device to focus and adjust its lighting level.

A doctor uses the Arclight in Rwanda
© Mrs Claire Morton, consultant ophthalmologist

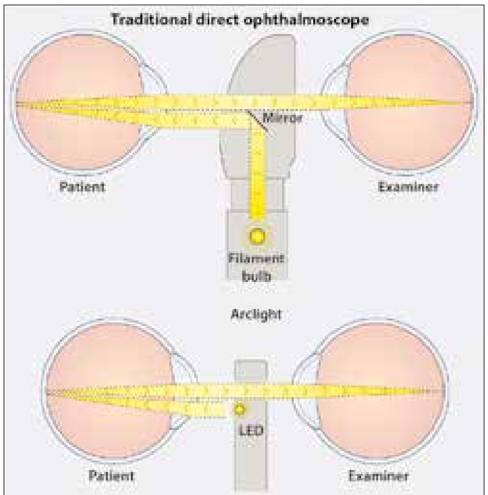
The current instrument includes a slot-in PCB (printed circuit board) module that has a micro USB port, and lenses so that it can be charged if needed, while an integrated solar panel means that it can be used as an 'off-grid' diagnostic tool. When a small plastic tube is added to the magnification loupe, the Arclight can be transformed into an octoscope to diagnose hearing conditions.

A study led by the International Centre for Eye Health in London revealed that the Arclight is at least as good as traditional ophthalmoscopes, and is better in some areas, such as size and ease of use. It has been listed as one of the International Agency for the Prevention of Blindness' recommended devices for use in low- and middle-income environments. More than 10,000 Arclights have been distributed in over 50 countries, including Malawi, Ghana, Ethiopia, Rwanda, Fiji, Indonesia and the Solomon Islands.

While this version of the Arclight is already changing lives, version three will include internal memory loaded with teaching resources for clinicians in remote areas. The teaching tools can be viewed by attaching a mobile phone without the need for an internet connection.

The company hopes that Arclight will become more widely available in communities where it is needed. By selling the devices to doctors in richer countries at a profit, a social enterprise run through the University of St Andrew's global health team have helped to fund the roll-out of cost-price devices in poorer communities.

For further information, visit **arclightscope.com**



A diagram shows how the Arclight's LED differs from the traditional bulb and mirror

Words: Sarah Griffiths

HOW DOES THAT WORK?

BLOCKCHAIN

Blockchain technology records secure online transactions through a shared and continually reconciled database. Originally created in 2009 to manage the digital currency bitcoin, it is now being considered for applications as diverse as online voting and cloud storage.

A blockchain is a distributed database, meaning that each participant can access the whole database and its complete history. This means that no single person or group controls the data, and everyone can verify the records, which are permanent. A blockchain is made up of nodes, computers that connect to the blockchain network and receive a copy of the blockchain. These nodes communicate with each other, storing and updating information rather than being updated through one central computer.

The concept was invented to ensure that bitcoin could work in the same way as cash, able to move about without being spent multiple times by the same person, without the use of a bank. The database contains the payment history of every bitcoin, so can provide proof of who owned it at any given time.

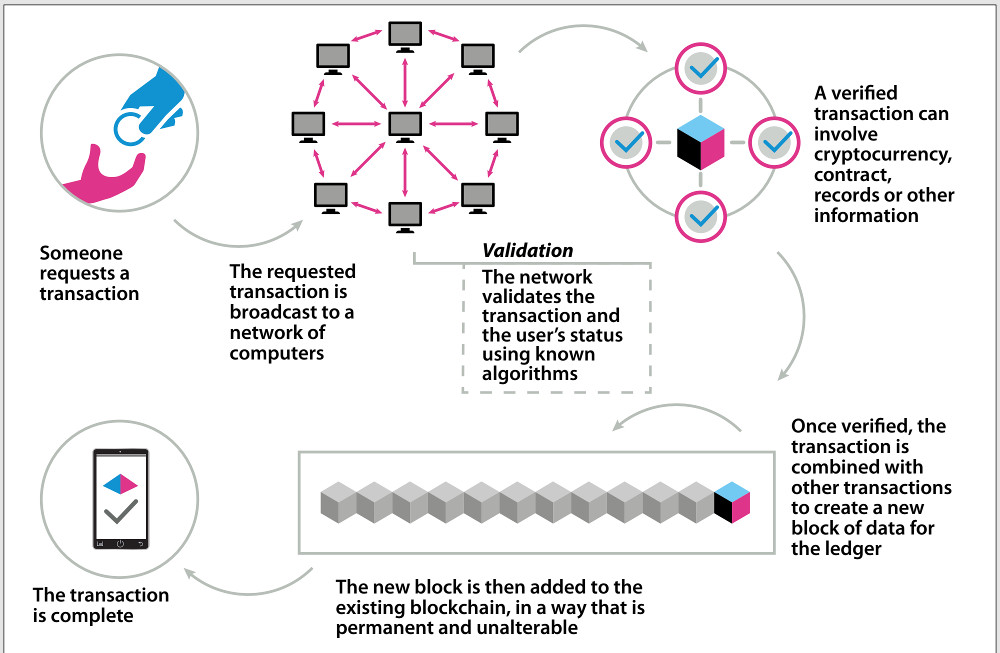
Every transaction on a blockchain can be viewed by anyone with access to the system, with each user or node having a unique address. After confirming that the transaction is legitimate, the blockchain database puts the record, along with a number of other verified transactions, into a block and timestamps them before chaining them together using a cryptographic signature. These new encrypted blocks are added to the previous blocks, creating a chain that shows the entire history of the blockchain.

Once a transaction has been added to the database, the accounts are updated and records cannot be altered, as they are linked to all previous transactions.

Blockchain databases are not stored in one single location, but are hosted by many computers simultaneously. This means that a blockchain database contains the history of all of its records, protected from being revised, deleted or tampered with. Consequently, hackers cannot corrupt the information without targeting all computers that the blockchain is held on, as well as all the previous blocks, creating a secure online system.

The databases can be created with a group of preselected participants, or they can be 'unpermissioned' and open to everyone, meaning that anyone can contribute data and everyone that has a copy of the ledger has an identical version.

In the future, blockchain technology could be used for most financial transactions. The Bank of England has said that blockchains or digital ledger technology may be a useful platform to power a central bank digital currency, something that is currently being researched. In 2014, blockchain was used by a Danish political party for electronic voting at its annual meeting, laying the foundations for blockchain use in general elections. There are also multiple startups that are currently looking into creating blockchain-based cloud storage systems, which would eliminate hacking and data loss problems that often arise in traditional cloud storage.



The cycle of a blockchain transaction