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DEPARTMENT OF ENGINEERING

NEWS

UNIVERSITY OF CAMBRIDGE

In this issue

Double the impact of your gift

The Harding Challenge

You may have already heard about the Harding Challenge from your College, but did you know a gift to your department could also qualify?

If you are a new donor to the Collegiate University, or have not given since July 2019, your gift to support students in your department will be eligible for the Harding Challenge. As such, your gift will unlock, pound for pound, a contribution to a special fund for undergraduate financial support, benefitting both your department and undergraduates in greatest need across Cambridge.

This time-limited challenge is the first time Collegiate Cambridge has come together in a fundraising effort to extend the impact of a donor's gift, which enables us to do more for undergraduates than ever before.

For more information, please contact our Senior Associate Director for Engineering: Victoria.Thompson@admin.cam.ac.uk

Cover image: Alumna Farah Alibay, systems engineer at NASA's Jet Propulsion Laboratory, stands in front of OPTIMISM, the Earth replica of the Mars Perseverance rover used for testing in the Mars Yard. Credit: JPL / Caltech.

Note from the editors

In support of our worldwide reputation for first class academic research, the Department has a Design and Technical Services team that delivers a manufacturing service available to all teaching and research activities in the Department.

The team is equipped with a range of both manual and computer controlled machinery and makes extensive use of computer-aided design (CAD), electronics development and manufacturing facilities, as well as traditional trades.

It is a service that took centre stage recently in two separate research projects:

Working in collaboration with the Automating Concrete Construction (ACORN) researchers to develop a modular "pin-bed" solution that uses an array of computer-controlled pistons (actuators) that move vertically to support and deform a flexible formwork of composite strips and a fabric membrane to create a mould for concrete. When challenged to realise the ACORN vision, the workshop team took inspiration from a project developed for the Whittle Laboratory, adapting this tried and tested solution to meet the researchers' specifications. **See page 4**

In support of Senior Research Associate, Dr Christopher Cleaver's early-stage company, DeepForm, which is developing a new method of producing car parts using half the metal, the on-site workshop team helped to weld and assemble a new rig for metal forming. This also involved the machining and cutting of metal and the design and installation of an electrical control cabinet to control the motors. The end result is quite impressive! **See page 11**

Charlotte Hester and Jacqueline Saggers

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Head's welcome

Credit: Graham CopeKoga

When I gave the traditional annual address to the staff and students of the Department last November, it looked as if the pandemic was nearly over. At that point, we had not heard of Omicron. We were thinking about getting back to normal. We did not imagine the impact of the new virus variant or that there would be a major war in Europe. In just four months, the world has changed significantly. However, experience tells us that we must expect the unexpected and constantly adapt. Another example is climate change. COP26 showed that we are only gradually learning the full nature of the problems involved and the measures that will be needed to address them. Most importantly, engineers will always have an important part to play in managing change, addressing problems and mitigating disasters.

The education of the next generation of engineers is a major part of our mission as a department. We must do this in a way that is resilient to change: that remains useful and relevant throughout the careers of the students, even if the world around them is very different from the world in which we delivered our course. This means that we need to teach at least some material that is fundamental and that does not change. Such basic principles can be applied in a wide variety of contexts, some of which cannot yet be imagined. This is why the first two years of our undergraduate course evolve relatively slowly. They contain material that is very broadly relevant. It provides a starting point for young engineers on which they can build up specialist knowledge. It supports people during the middle years of their careers, when they need to understand the principles that underpin the specialists that are reporting to them.

The second two years of our course build on the broad basis of the first two and add more specialised and up-to-date material. Somewhat confusingly, the fact that this material is more focused and relevant to today's problems, may also make some of it less relevant to the problems of the future. We therefore offer a constantly changing mixture of more than 80 modules that open a window on the excitement and challenges of modern engineering.

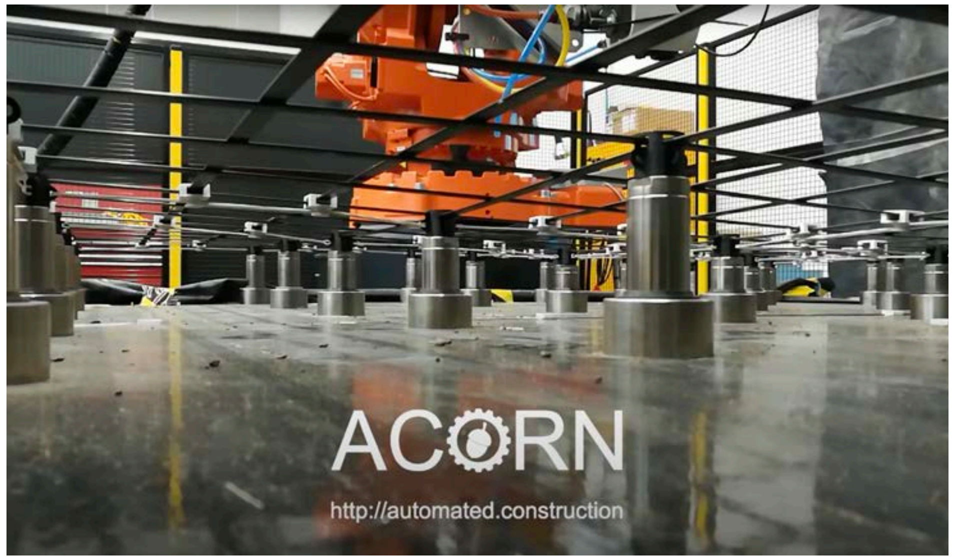
The way we teach is also changing. We have been working on technology-enhanced learning techniques for at least the last 20 years, although this has gone under a number of different names. The pandemic accelerated the development of this and forced us to deliver almost everything online. This has left us with new tools and useful experience that we can use to enrich all our teaching in the future. New tools like these open up new possibilities, but they do not change the fundamental underlying goal of educating engineers in a way that will support them through the changes they will experience over their complete careers.

We have also engaged enthusiastically in the University's new programme of online courses for mid-career graduate professionals called *Cambridge Advance Online* (https://advanceonline.cam.ac.uk). Professor Jan Maciejowski is offering a course on Control Engineering; Professor Nathan Crilly is offering a course on Creativity, Problem Solving and Design Thinking; Dr Rob Phaal and colleagues from the Institute for Manufacturing (IfM) are offering a course on Product Technology Roadmapping; Kasia Lanucha from the Engineering Department Centre for Languages and Inter-Communication is offering a course on Intercultural Communication for Global Business; and Dr Russell Hunter is offering Leveraging Big Data for Business Intelligence. This new type of educational offering gives us an opportunity to engage with a broader audience from different backgrounds, disciplines and career stages. It helps us to develop new educational skills that are also relevant to our residential degree programmes.

The educational role of the Department will adapt and grow, as indeed it must, in response to a changing world. But this adaptation and growth does not involve following transitory fashions or diluting the analytical backbone of the course; it is strongly anchored in our historical strengths. It builds on the focus on fundamental principles which we know gives our students resilience and adaptability for the future. It involves new teaching techniques, not just for the sake of it, but where they are relevant and appropriate. In this way, our undergraduate and graduate teaching will remain one of the most valuable things that we do, and a contribution of which we can be proud.

Professor Richard Prager FREng, FIET, CEng

→ A modular “pin-bed” solution that uses an array of computer-controlled pistons (actuators) that move vertically to support and deform a flexible formwork of composite strips and a fabric membrane



New concrete mould system uses the right amount of concrete and no more

Concrete is the world’s most widely consumed material after water and its production contributes to more than 7% of global CO_2 emissions. Achieving global ambitions to limit warming to 1.5ºC will require significant change across the construction sector – not least in how we use concrete.

An easy win is simply to use less concrete by eliminating waste and overdesign. This is the focus of the UKRI-funded research project “Automating Concrete Construction (ACORN)”.

ACORN is researching how digital design and automated production methods can be used to create concrete floor systems with drastically reduced CO_2 emissions. This is achieved using a segmented thin-shell floor solution that can be produced off-site using robotics, and is designed to be transportable, demountable, and reusable at the end of its first life, enabling circularity in construction.

This interdisciplinary project includes researchers from the Universities of Bath, Cambridge and Dundee. The research team in Cambridge, led by Dr John Orr, is working towards the realisation of a real-scale demonstrator of a 4.5 m x 4.5 m shell floor system. Their research is making use of new construction robotic facilities held within the National Research Facility for Infrastructure Sensing (NRFIS).

The fabrication of a segmented concrete shell required the team to design and fabricate an entirely new reusable and reconfigurable concrete mould that is compatible with their robotic spraying system. The realisation of this new mould demonstrates collaboration between the research team and the Department of Engineering workshops.

The Department of Engineering’s in-house design team worked with ACORN researchers to develop a modular “pin-bed” solution that uses an array of computer-controlled pistons (actuators) that move vertically to support and deform a flexible formwork of composite strips and a fabric membrane to create a mould for concrete.

Thanks to this mould, the team can cast concrete shell segments, whether identical or different, with a single mould. This system allows mass-customisation and significantly reduces the waste and carbon content due to the necessary formwork of these elements, but more complex to build, curved structures.

When challenged to realise the ACORN vision, the workshop team took inspiration from a project developed for the Whittle Laboratory, adapting this tried and tested solution to meet their specifications.

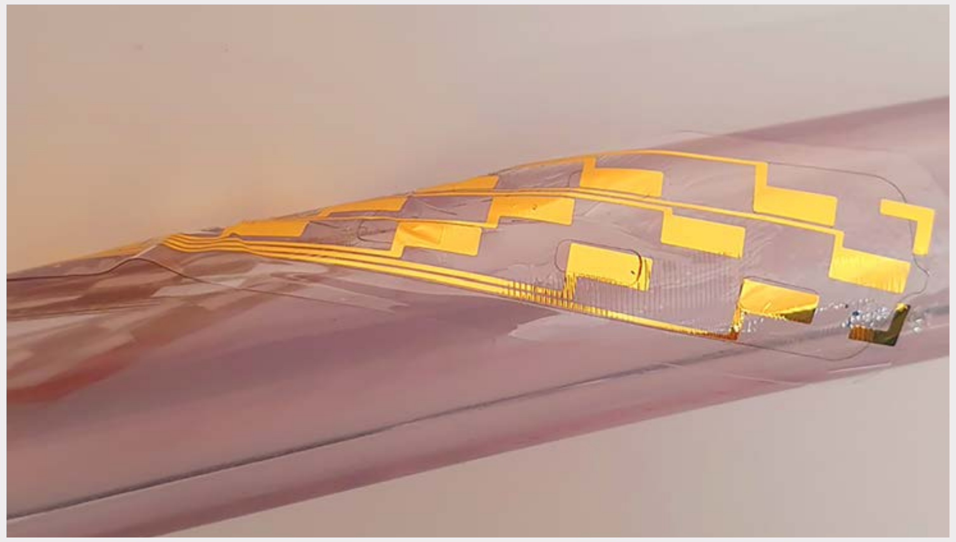
Senior Design Engineer Neil Houghton said: “Using a proven design, adopted from an entirely unrelated research project, effectively de-risked this significant mechanical development and demonstrates the value of sharing technical know-how between entirely different research applications. This collaboration benefited the ACORN vision in terms of cost, timescales, effort and technical risk.”

Cambridge lead investigator Dr John Orr said: “The collaboration between our research team, the professional services team in the workshop and our fabrication group allowed us to realise a new concrete mould that will demonstrate the industrial feasibility of using a segmented thin shell concrete floor system. This has the potential to drastically reduce the amount of concrete used in our buildings and enables a circular economy, as we have built in the potential for future reuse. The project has benefited enormously from the expertise within the Department and from the input of our industrial steering group, made up of 12 of the UK’s largest civil and structural design and construction companies.”

With this demonstrator and the future release of an open source version of the end-to-end design and fabrication tool, ACORN fuses the digital and physical realms and hopes to drive the acceptance of a new culture in the construction industry: to use enough material – and no more.

Watch the new concrete mould system in action: youtu.be/wUxkT4vSAKA
http://automated.construction
nrfis.cam.ac.uk
dts.eng.cam.ac.uk

Inflatable, shape-changing spinal implants could help treat severe pain



A team of engineers and clinicians has developed an ultra-thin, inflatable device that can be used to treat the most severe forms of pain without the need for invasive surgery.

The device uses a combination of soft robotic fabrication techniques, ultra-thin electronics and microfluidics. The device is so thin – about the width of a human hair – that it can be rolled up into a tiny cylinder, inserted into a needle, and implanted into the epidural space of the spinal column, the same area where injections are administered to control pain during childbirth.

Once correctly positioned, the device is inflated with water or air so that it unrolls like a tiny air mattress, covering a large section of the spinal cord. When connected to a pulse generator, the ultra-thin electrodes start sending small electrical currents to the spinal cord, which disrupt pain signals.

Early tests of the device suggest that it could be an effective treatment for many forms of severe pain – including leg and back pain – which are not remedied by painkillers. It could also be adapted into a potential treatment for paralysis or Parkinson’s disease. However, extensive tests and clinical trials will be required before the device can be used on patients.

Although other types of spinal cord stimulation devices are currently used to treat severe pain, the most effective of these devices are bulky and require invasive surgery, while current keyhole devices are far less effective at treating pain. By combining the clinical effectiveness of the surgical devices and the ease of implantation of the keyhole devices, the Cambridge-developed device could be an effective, long-term solution to intractable pain, which affects millions worldwide. The results are reported in the journal *Science Advances*.

Pain is something that everyone experiences, and for the vast majority of people it is temporary and treatable. However, for some, pain becomes debilitating. In the UK, back pain is the leading cause of disability, costing the economy around £12 billion per year. In the US, the Centers for Disease Control and Prevention estimates that as many as one in 12 Americans suffers from intractable back pain that does not respond to conventional treatments such as non-steroidal anti-inflammatory drugs (NSAIDs) or opioids.

Spinal cord stimulation (SCS) is an option for those who suffer from intractable back pain or other types of neuropathic pain, but despite its effectiveness its use is limited, with just 50,000 procedures carried out worldwide each year.

“Spinal cord stimulation is a treatment of last resort, for those whose pain has become so severe that it prevents them from carrying out everyday activities,” said Dr Damiano Barone from Cambridge’s Department of Clinical Neurosciences, one of the paper’s senior authors. “However, the two main types of SCS devices both have flaws, which may be one reason their use is limited, even though millions struggle with chronic pain every day.”

The most effective SCS device in clinical use is a paddle-type device, which covers a wide area of the spinal cord but is bulky and requires invasive surgery under general anaesthetic. The other type of device can be implanted with a needle and only requires local anaesthetic, but it covers a smaller area and is less clinically effective than a paddle-type device.

“Our goal was to make something that’s the best of both worlds – a device that’s clinically effective but that doesn’t require complex and risky surgery,” said Dr Christopher Proctor from Cambridge’s Department of Engineering, the paper’s other senior author. “This could help bring this life-changing treatment option to many more people.”

“In order to end up with something that can be implanted with a needle, we needed to make the device as thin as possible,” said co-first author Ben Woodington, also from the Department of Engineering.

The researchers used a combination of manufacturing techniques to build their device: flexible electronics used in the semiconductor industry; tiny microfluidic channels used in drug delivery; and shape-changing materials used in soft robotics.

Their finished device is just 60 microns thick – thin enough that it can be rolled up and placed in a needle for implantation. However, after implantation the device expands to cover a wide area of the spinal cord, thanks to the microfluidic channels.

“Thin-film electronics aren’t new, but incorporating fluid chambers is what makes our device unique – this allows it to be inflated into a paddle-type shape once it is inside the patient,” said Dr Proctor.

The researchers validated their device *in vitro* and on a human cadaver model. They are currently working with a manufacturing partner to further develop and scale up their device and are hoping to begin tests in patients within two to three years.

Take a closer look at the device: youtu.be/afdn5Tdlbq8

→ Tennis match

For the brain, context is key to new theory of movement and memory

Credit: Chino Rocha on Unsplash

Mathematical model could help in physical therapy and shed light on learning more generally.

How is it that a chef can control a knife to fillet a fish or peel a grape and can wield a cleaver just as efficiently as a paring knife? Even those of us less proficient in the kitchen learn to skilfully handle an astonishing number of different objects throughout our lives, from shoelaces to tennis rackets.

This ability to continuously acquire new skills, without forgetting or degrading old ones, comes naturally to humans but is a major challenge even for today's most advanced artificial intelligence systems.

Scientists from the University of Cambridge and Columbia University have developed and experimentally verified a new mathematical theory that explains how the human brain achieves this feat. Called the COntextual INference (COIN) model, it suggests that identifying the current context is key to learning how to move our bodies.

The model describes a mechanism in the brain that is constantly trying to figure out the current context. The theory suggests that these continuously changing beliefs about context determine how to use existing memories — and whether to form new ones.

"Imagine playing tennis with a different racket than usual or switching from tennis to squash," said co-senior author Dr Daniel Wolpert from Columbia University. "Our theory explains how your brain adjusts to these situations and whether to treat them as distinct contexts."

According to the COIN model, the brain maintains a repertoire of motor memories, each associated with the context in which it was created, such as playing squash versus tennis. Even for a single swing of the racket, the brain can draw upon many memories, each in proportion to how much the brain believes it is currently in the context in which that memory was created.

This goes against the traditional view that only one memory is used at a time. To improve performance on the next swing, the brain also updates all memories, once again depending on its belief about the current context. When the context of the movement is judged to be new, the brain automatically creates a new memory for that context. This ensures that we do not overwrite previously established memories.

This research may lead to better physical therapy strategies to help people with injuries use their bodies again. Often the improvements seen in the setting of a physical therapist's office do not transfer to improvements in the real world.

"With a better understanding of how context affects motor learning, you can think about how to nudge the brain to generalise what it learns to contexts outside of the physical therapy session," said first author Dr James Heald. "A better understanding of the basic mechanisms that underlie the context dependence of memory and learning could have therapeutic consequences in this area."

Practice with a tennis racket, and the brain forms motor memories of how you moved your arm and the rest of your body that improve your serve over time. But learning isn't as simple as just making better memories to make movements more precise, the researchers said. Otherwise, a tennis player's serves might improve to the point at which they never hit a ball out of bounds. The real world and our nervous systems are complex, and the brain has to deal with a lot of variability.

How does the brain distinguish this noise — these random fluctuations — from new situations?

The answer, according to the COIN model, may be Bayesian inference, a mathematical technique used to deal with uncertainty. This method statistically weighs new evidence in light of prior expectations in order to update one's beliefs in a changeable world. In the COIN model, a context is a simplifying assumption that, in a given set of circumstances, certain actions are more likely to lead to some consequences than others.

The model also predicted that a learned skill can re-emerge even after subsequent training seems to have erased it. Called spontaneous recovery, this re-emergence is seen in many other forms of learning besides motor learning. For example, spontaneous recovery has been linked with challenges in treating post-traumatic stress disorder, where contexts can trigger traumatic memories to spontaneously recur.

Scientists usually explain spontaneous recovery by invoking two different learning mechanisms. In one, memories learned quickly are forgotten quickly, and in the other, memories learned slowly are forgotten slowly, and can thus reappear. In contrast, the COIN model suggests there is just one mechanism for learning instead of two separate ones, and that memories that apparently vanished may be ready to pop back with the right trigger: the belief that the context has re-emerged. The researchers confirmed this in their lab with new experiments.

"What I find exciting is that the principles of the COIN model may also generalise to many other forms of learning and memory, not just memories underlying our movement," said co-senior author Professor Máté Lengyel. "For example, the spontaneous recurrence of seemingly forgotten memories has been observed both in motor learning and in post-traumatic stress disorder."

www.eng.cam.ac.uk/profiles/ml468

→ Alex Kendall, Wayve co-founder and CEO

ALUMNI UPDATE

Meet Alex Kendall – the autonomous vehicle pioneer with global ambition

Credit: Wayve

When Alex Kendall co-founded Wayve in 2017, he foresaw autonomous vehicles (AVs) with the intelligence to make their own decisions based on what they see with computer vision. Fast-forward five years and the start-up is pioneering an artificial intelligence (AI) led approach to AVs on a global scale, using the embodied intelligence of an end-to-end deep learning system that continually learns from driving data.

January 2022 marked an important milestone for Wayve CEO Alex and his team, as the London-based start-up announced it had secured investment of $200 million in its Series B funding round to accelerate the development of AV2.0 – the next wave of AVs.

Wayve is reimagining autonomous mobility. Its AI software, lean camera-first sensing suite and fleet learning platform for AV2.0 is designed to be the most adaptable AV system for fleet operators, one which can quickly and safely adapt to new driving domains anywhere in the world.

Wayve – the early days

It was during his PhD in Deep Learning, Computer Vision and Robotics, under the supervision of Professor Roberto Cipolla in the Machine Intelligence Laboratory, that the groundwork for what would become Wayve began to take shape.

In 2015, Alex contributed to developing a novel deep learning algorithm for semantic segmentation – SegNet – a practical algorithm to achieve accurate real-time pixel-level recognition on real driving sequences. The research was published in the journal *IEEE Transactions on Pattern Analysis and Machine Intelligence* and is one of the journal's and research field's most cited papers.

The early work that led to this paper was first funded by Toyota in 2007 and resulted in Professor Cipolla's team building a fully labelled/annotated database (CamVid) of urban road scenes and driving videos, with each pixel in every image labelled by hand as belonging to one of 12 classes of object or background (Brostow et al; 2009). Using this data, the Cambridge team then trained state-of-the-art machine learning algorithms for segmenting and labelling each pixel (Shotton et al; 2008 and Badrinarayanan et al; 2015). In later years, Vijay Badrinarayanan and Jamie Shotton both joined Alex at Wayve as VP Autonomy (2020) and Chief Scientist (2021) respectively.

In a recent blog post, Alex said: "I was fortunate enough at this time (2014-2017) to be studying computer vision and deep learning for my PhD at the University of Cambridge, with a supervisor and an environment that encouraged entrepreneurship. Our award-winning research showed for the first time that it was possible to use deep learning to teach a machine to understand where it is and what's around it, plus crucially understand what it doesn't know.

"With this breakthrough technology, I imagined we could now move away from what we predicted to be the prohibitive hurdles to scale such as HD-maps, LiDAR and rules-based autonomy, towards machines that have the intelligence to make their own decisions based on what they see with computer vision.

"Wayve began in a garage, developing a Driving Intelligence. The results were quickly promising. For the first time in the world, we showed a reinforcement learning system learning to drive a real-life autonomous vehicle from computer vision. In our first year, we demonstrated model-free and model-based reinforcement learning driving our car, sim2real and more.

"In five quick years, we established the necessary ingredients to pioneer AV2.0: data, compute, partnerships, operations and – most importantly – our team. We've solved the fundamental technical challenges and earned the right to build AV2.0 at scale."

Wayve – the next chapter

Using machine learning, Wayve is building a more scalable AV platform that can adapt its driving intelligence to new cities, different use cases and vehicle types, both quickly and safely. This unlocks the potential to scale commercial deployments to other cities more quickly than the conventional AV approach, which typically relies on an expensive and complex array of sensors and is operationally limited by high-definition (HD) maps and rules-based control strategies. Wayve aims to be the first to deploy autonomy in 100 cities.

Wayve's AV2.0 technology learns from petabyte-scale driving data provided by its commercial partner fleets.

The latest round of funding brings total equity raised to $258 million since inception and reinforces Wayve's position as a leader in autonomous driving.

wayve.ai

Credit: Goh Rhy Yan on Unsplash

Real-time drone intent monitoring could enable safer use of drones

Real-time drone intent monitoring could enable safer use of drones and prevent a repeat of 2018 Gatwick incident.

Researchers have developed a real-time approach that can help prevent incidents like the large-scale disruption at London's Gatwick Airport in 2018, where possible drone sightings at the perimeter of the airport caused the cancellation of hundreds of flights.

The researchers used a combination of statistical techniques and radar data to predict the flight path of a drone, and whether it intends to enter a restricted airspace, for instance around a civilian airport.

Their solution could help prevent a repeat of the Gatwick incident, as it can spot any drones before they enter restricted airspace and can determine, early, if their future actions are likely to pose a threat to other aircraft.

This new predictive capability can enable automated decision-making and significantly reduce the workload on drone surveillance system operators by offering actionable information on potential threats to facilitate timely and proportionate responses.

Real radar data from live drone trials at several locations was used to validate the new approach.

Drones have become ubiquitous over the past several years, with widespread applications in agriculture, surveying and e-commerce, among other fields. However, they can also be a nuisance or present a potential safety risk, especially with the wide availability of cheap and increasingly more capable platforms.

A few days before Christmas 2018, reported drone sightings near the perimeter of Gatwick Airport caused hundreds of flights to be disrupted due to the possible risk of collision. No culprit was found.

"While we don't fully know what happened at Gatwick, the incident highlighted the potential risk drones can pose to the public if they are misused, whether that's done maliciously or completely innocently," said paper co-author Dr Bashar Ahmad. "It's crucial for future drone surveillance systems to have predictive capabilities for revealing, as early as possible, a drone with malicious intent or anomalous behaviour."

To aid with air traffic control and prevent any possible collisions, commercial airplanes report their location every few minutes. However, there is no such requirement for drones.

"There needs to be some sort of automated equivalent to air traffic control for drones," said Professor Simon Godsill, who led the project. "But unlike large and fast-moving targets, like a passenger jet, drones are small, agile, and slow-moving, which makes them difficult to track. They can also easily be mistaken for birds, and vice versa."

"We need to spot threats as early as possible, but we also need to be careful not to overreact, since closing civilian airspace is a drastic and highly disruptive measure that we want to avoid, especially if it ends up being a false alarm," said first author Dr Jiaming Liang, who developed the underlying algorithms with Professor Godsill.

There are several potential ways to monitor the space around a civilian airport. A typical drone surveillance solution can use a combination of several sensors, such as radar, radio frequency detectors and cameras, but it's often expensive and labour-intensive to operate.

Using Bayesian statistical techniques, the researchers built a solution that would only flag those drones that pose a threat and offer a way to prioritise them. Threat is defined as a drone that's intending to enter restricted airspace or displays an unusual flying pattern.

"We need to know this before it happens, not after," said Professor Godsill. "This way, if a drone is getting too close, it could be possible to warn the drone operator. For obvious safety reasons, it's prohibited to disable a drone in civilian airspace, so the only option is to close the airspace. Our goal is to make sure airport authorities don't have to do this unless the threat is a real one."

The software-based solution uses a stochastic, or random, model to determine the underlying intent of the drone, which can change dynamically over time. Most drones navigate using waypoints, meaning they travel from one point to the next, and a single journey is made of multiple points.

In tests using real radar data, the solution was able to identify drones before they reached their next waypoint. Based on a drone's velocity, trajectory and other data, it was able to predict the probability of any given drone reaching the next waypoint in real time.

www.eng.cam.ac.uk/profiles/sjg30

Meet Yaw Ansong Snr – engineer, medical doctor and entrepreneur

Credit: Yaw Ansong Snr

From a young age, Yaw Ansong Snr taught himself how to program computers and this sparked his love for engineering. In October 2021, he began a PhD in the Department's Bionic Systems Group. We caught up with Yaw to reflect on his successes to date and to find out more about his research in neurotechnology.

I am Ghanaian and I have lived the majority of my life in Ghana. When I was a little boy, my mum got me a computer as a gift (quite interesting in retrospect, considering my mum is not tech-savvy). This is what fuelled my love for engineering. I taught myself how to program computers, and as a child I enjoyed building computer games and apps with my childhood start-up. Albeit a hobbyist, I managed to make money from them.

Along the way, I became interested in medicine and thought of combining the best of both worlds. I firmly believe innovation is in the intersection; thus, one of my core goals has been to leverage technology to improve health outcomes in society. Unfortunately, in Ghana, intercalated Doctorate of Medicine and of Philosophy (MD–PhD) programmes are non-existent. This means anyone interested in becoming a physician-scientist must first finish one, then the other, making for a longer duration of study. They must also be prepared to teach themselves many things. This has pretty much been my journey. I studied for my Bachelor of Medicine and Bachelor of Surgery (Mb ChB) at the University of Cape Coast.

I am very excited to join the Bionic Systems Group, which was highly recommended to me by PhD students in the neurotech community. I reached out to the Principal Investigator Dr Christopher Proctor, because my research interest in minimally invasive implants and electronic drug delivery aligns with his. I revel in the opportunity to work with him. He has been incredibly helpful and accommodating. I was primarily looking for an enabling environment that would challenge me to grow as an entrepreneur as well as a scientist. I am very thankful to have been selected as one of five PhD scholarship recipients, awarded by the Cambridge Trust via Cambridge-Africa, for the 2021 academic year, as well as a recipient of the Honorary Trinity-Henry Barlow award from Trinity College.

My PhD research is on neurotech for primary treatment of the spinal cord following injury. The goal is to explore a new, clinically translatable treatment modality for Spinal Cord Injuries (SCIs). Research has shown that an electric field can guide neural growth and migration. On this premise, as well as other evidence-based knowledge, the goal is to build an implantable device that would aid in the regeneration of nerve tissues. This is potentially promising because it aims at functional recovery and not just improving quality of life following SCIs. There are many factors to consider, from choosing the type of material to use, to the appropriate fabrication method, to control systems. It is an exciting area to research.

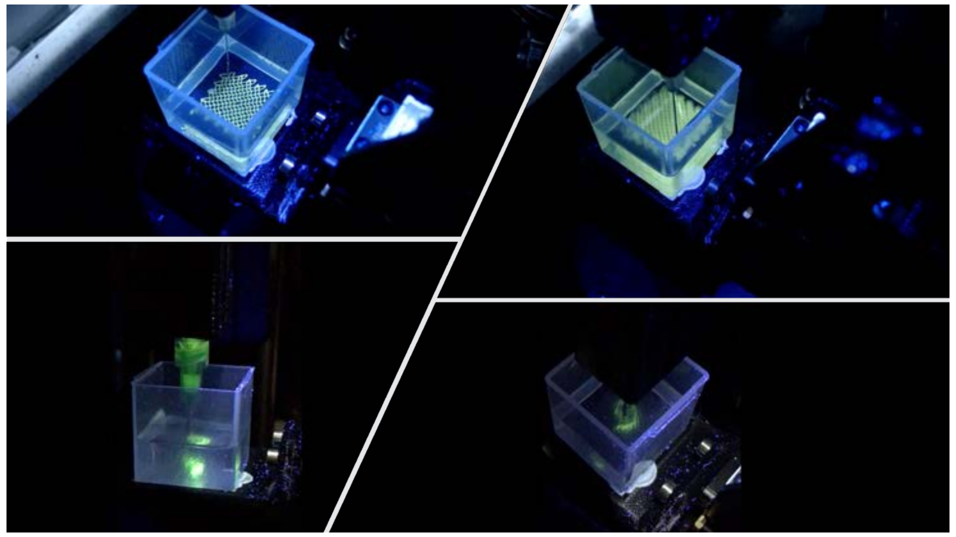
Choosing to study neurotechnology was a very easy decision – the cross-disciplinary nature of neurotech makes it the perfect field. I found 'traditional' bioengineering courses to be quite boring and I wanted an exciting engineering discipline that would potentially make use of all the skill set I had acquired over the years.

I am also a serial entrepreneur with a soft robotics start-up, the goal of which is to explore the potential of this technology to solve interesting healthcare problems for the greater good of society. I began working on the start-up following my Master's degree in Biomedical Engineering (Neurotechnology) at Imperial College London. There are many practical use cases for soft robotics in healthcare. During my degree, I was fortunate to be introduced to soft robotics by a kind professor I had approached for advice on a thesis topic. I fell in love with soft robotics and ended up building a soft-robotic peristaltic device that leveraged pneumatic actuation for my thesis. The degree programme also afforded me the opportunity to learn a bit more about rigid robotics via the *Human Neuromechanical Control and Learning* module.

Overall, my journey has required an incredible amount of self-discipline, perseverance and fortitude. For anyone interested in applying to Cambridge, I would encourage you to do so, because you miss 100% of the shots you do not take. I chose Cambridge because I find the research work, particularly at the Department of Engineering, to be cutting edge and very intriguing. In addition, Silicon Fen as well as the incubator programme at the University of Cambridge provide the perfect environment that I seek as an entrepreneur. Finally, Cambridge-Africa's goal of prioritising research in Sub-Saharan Africa gives me a soft spot for the University.

bionicsystems.eng.cam.ac.uk

→ The fabrication process of a biomimetic cochlea: creating an electro-mimetic bone matrix (top images) and a spiral-shaped cochlear structure within the matrix (bottom images)



Credit: Iek Man Lei

New research to improve cochlear implants for users

A team of engineers and clinicians have used 3D printing to create intricate replicas of human cochleae – the spiral-shaped hollow bone of the auditory inner ear – and combined it with machine learning to advance clinical predictions of ‘current spread’ inside the ear for cochlear implant (CI) patients. ‘Current spread’ or electrical stimulus spread, as it is also known, affects CI performance and leads to ‘blurred’ hearing for users, but no adequate testing models have existed for replicating the problem in human cochleae – until now.

CIs have transformed the lives of hundreds of thousands of people who suffer from severe or profound hearing loss. However, the efficacy of the surgically implanted medical device has been hampered by ‘current spread’ – a phenomenon caused by the high electrical conductivity of the fluids that sit inside cochlear ducts. These fluids prevent the CI user’s auditory nerve from being stimulated accurately, leaving many users experiencing significant distortions to the sounds they perceive.

The size and shape of a human cochlea is unique to each individual and varies from person to person. Coupled with its tricky location and complex anatomy, this makes it one of the most difficult tissues to study and thus, analysis of the ongoing problem of ‘current spread’ has not been easily possible.

Now a cross-disciplinary research team[1] have been able to analyse the electric field imaging data of cochlear implant patients, thanks to 3D printed cochleae with tuneable electro-anatomy. The 3D printed models allow the researchers to study how the cochlear shape and electrical property of the biomimetic cochleae affects ‘current spread’ measured in electric field imaging. Once combined with machine learning, this co-modelling method can predict the ‘current spread’ in cochlear implant users, and for the first time extrapolate the range of patient cochlear tissue resistivity. The results are reported in the journal *Nature Communications*.

Ms Iek Man Lei, primary author of the study and a PhD student from the Biointerface Research Group at Cambridge, said: “Our library of 3D printed cochlear models capture the range of geometries that human cochlear lumens can take and are designed with electro-mimetic bone matrices that replicate realistic bone resistivities. The 3D printed cochlear models also have suitable mechanical property for multiple CI electrode insertion. Our ‘print-and-learn’ co-modelling concept can help decipher how different characteristics of a patient’s cochlea affect the stimulus spread.”

Professor Manohar Bance, Professor of Otology and Skull Base Surgery from Addenbrooke’s Hospital, said: “The next steps are to use this co-modelling approach to understand patient electrical field imaging in different disease states e.g. otosclerosis (a rare condition that causes hearing loss). This will help us to understand if there are different cochlear conductivities in disease states, which could lead to unwanted stimulation of other structures such as the facial nerve. It will also help us diagnose patients who are experiencing unusual sound sensations to try to understand if their conductive pathways are different. In the bigger picture, we plan to go on from here to try to print electrically analogue whole heads to understand current pathways from implant to ground electrode on the implant, in order to better mimic the *in vivo* condition.”

Dr Shery Huang, Associate Professor in Bioengineering and Group Leader of the Biointerface Research Group at Cambridge, said: “We are all aware of the tremendous power of artificial intelligence (AI), but AI needs to start its learning from a good set of data. Because of patient privacy, patient safety and ethical concerns, holistically documented and characterised clinical data are hard to come by. Therefore, 3D printing is a powerful tool to create physical models that might provide a well-characterised training dataset as a purpose-built surrogate to clinical data for machine learning. The co-modelling principle demonstrated in this study could be useful to address other areas of clinical modelling and healthcare applications.”

This work was supported by the European Research Council, the Cambridge Hearing Trust and the Evelyn Trust.

[1] From the Department of Engineering; The Nanoscience Centre; Department of Clinical Neurosciences; Addenbrooke’s Hospital; Department of Physiology, Development and Neuroscience; University of Oxford; Tsinghua University; and University of Macau.

biointerface.eng.cam.ac.uk

Credit: Charlotte Hester

↑ Dr Christopher Cleaver of DeepForm and the new rig for metal forming situated in the Department of Engineering

Entrepreneurial postdocs win investment for innovative commercial ventures

The winners of The Chris Abell Postdoc Business Plan Competition 2021 have been announced. Dr Alex Justin won second prize for his early-stage company, Cambridge Conduits, which is developing bioengineered tissue grafts, and Dr Christopher Cleaver won third prize for his early-stage company, DeepForm, which is developing a new method of producing car parts using half the metal.

Run by Cambridge Enterprise and the Entrepreneurial Postdocs of Cambridge (EPOC), the competition has become a key annual event in the University’s entrepreneurial ecosystem.

Cambridge Conduits

Dr Justin works in the field of tissue engineering, which seeks to generate new biological tissues and organs for transplant. As part of the Markaki group, his PhD at the Department of Engineering focused on vascularisation, which is considered a key problem in the fabrication of replacement tissue in the lab. Following his PhD, Dr Justin took up a postdoctoral position at the Department in which he investigated methods for the bioengineering of tubular grafts. His proposal is for the development of next-generation, off-the-shelf, bioengineered vessels that can serve as a replacement for a wide range of diseased or damaged tissues in the human body.

Dr Justin won an investment prize of £10,000.

“Our collagen-based tubular grafts can be manufactured rapidly and inexpensively, without the use of cells, greatly reducing the regulatory burden and potentially enabling their use worldwide,” he said. “We have identified vascular access grafts for dialysis patients as an excellent beachhead opportunity in the vascular grafting space, where reducing infection rates and other complications is of paramount importance to improving clinical outcomes and reducing demand on healthcare providers.”

↑ Dr Alex Justin of Cambridge Conduits

However, vascular access grafts are just a first step, said Dr Justin. “We want to revolutionise the treatment of human disease through our bioengineered tissue grafts, generating complex tissue types in the future and enabling new surgical treatments hitherto untapped.”

He added: “With the investment prize we plan to embed ourselves in the customers’ environment, ensuring our designs meet the technical requirements of the surgeons and commercial requirements of hospitals.”

DeepForm

Dr Cleaver works on novel manufacturing processes for improved resource efficiency and productivity and is part of the The Use Less Group, based in the Department of Engineering. His research covers new ways of shaping metal components: flexible ring rolling, folding-shearing and flexible metal spinning. His proposal is to produce better car body parts with half the metal, helping automakers reach zero manufacturing emissions. DeepForm will be a technology provider to metal stampers and car manufacturers.

Dr Cleaver, who is leading the commercialisation effort, won an investment prize of £5,000.

“Sheet metal is a big contributor to a car’s embodied emissions and almost half the metal purchased to make car bodies is trimmed off as scrap during production – that’s 1% of the world’s industrial emissions. DeepForm is a technology that reduces the embodied CO_2 by up to 40%, offering better parts with a fraction of the scrap,” he said. “DeepForm offers a new way to do sheet metal stamping using a three-stage process: clamp – fold – shear.

“To date, our research has focused on isolated ‘shrink corners’ with straight sidewalls, a shape that is challenging to produce without incurring a wrinkling effect on the metal. In DeepForm, the sidewalls are folded into position, leaving an incompatible piece of metal, which is then gripped and sheared, minimising the amount of waste metal generated.”

In order to support Dr Cleaver’s research, the Department of Engineering’s Design and Technical Services on-site workshop team helped to weld and assemble a new rig for metal forming.

ALUMNI UPDATE

Meet Farah Alibay – the eyes and ears of robots on Mars

Credit: JPL / Caltech

As a child of the nineties, alumna Farah Alibay grew up enjoying outer space films such as *Apollo 13* and had dreams of one day becoming an astronaut. What captured her interest then – the exploration of other worlds – has since become the focus of her full-time job at NASA's Jet Propulsion Laboratory (JPL), the leading centre for robotic exploration of the solar system.

Farah, a systems engineer, shares details of her achievements to date, including one historic moment last year when she was part of the team that successfully flew a helicopter on Mars – the first powered, controlled flight by an aircraft on another planet. "Everything about that day was extraordinary," she said.

From Cambridge to NASA

It was shortly after Farah completed her Master's degree in Aerospace Engineering from Cambridge that she got the opportunity to intern at the Goddard Space Flight Center (GSFC) via the NASA Academy. There she helped develop tools for the Goddard Mission Design Laboratory (MDL), a lab set up for the development of space flight designs and architecture concepts. Farah credits the NASA Academy as being the internship experience that enabled her to discover her love for robotic planetary exploration, details of which she shares below.

Internships were invaluable to me as a young engineer. They allowed me to explore a range of different industries. I interned at Cobham, an aerospace and defence company, and at Bentley Motors while at Cambridge, and I spent a summer working in biofuel research in the south of India. I continued doing internships during my graduate studies, including one at NASA's GSFC after my Master's and two internships at the NASA JPL during my PhD.

Interning at the JPL felt like finally coming home. I fit right into the culture and atmosphere and knew that it was the place for me from the first day I set foot there. It was during my 2012 internship at the JPL that the Curiosity Rover landed on Mars and truly, that sealed the deal! I knew from then on that I wanted to be a part of the team that would eventually land the next large rover on the surface of Mars.

In my job at the JPL, I travel to other worlds through the eyes (cameras) and ears (microphones) of the robots that we send out there. Sometimes, I still pinch myself! Similar to what you experience when you study at Cambridge, at the JPL you are surrounded by extraordinary people, people who have pushed the boundaries of your field, who have written the textbooks that you have studied and who have paved the way before you. At first, it was quite humbling to be a part of these teams involved in robotic exploration of our solar system, but now I cherish every single moment.

Being a strong technical communicator and writer has become a key strength of mine. My Master's advisor at Cambridge went out of his way to teach me how to perform research and how to communicate those results in a coherent and well-structured manner. I gained some invaluable skills in teamwork, communication and writing. Furthermore, my Master's degree at Cambridge gave me a strong engineering baseline and a deep understanding of the key first principles that form the basis for most engineering disciplines.

Mission to Mars

Over the past seven years that Farah has been working at the JPL, she has been involved in many missions, including Mars Cube One (MarCO) that she worked on and oversaw from idea to delivery. Consisting of a pair of communications-relay CubeSats – a class of miniature spacecraft – MarCO travelled to Mars to perform Entry, Descent and Landing (EDL) telecommunications relay for the InSight mission in 2018. InSight is the first outer space robotic explorer to study in-depth the interior structure of Mars: its crust, mantle and core. MarCO was successful in helping the InSight lander communicate with Earth in real time.

While InSight went on to be Farah's first Mars landing, she also gained experience in human exploration through the Asteroid Robotic Redirect Mission (ARRM), a mission that has since been cancelled. ARRM had intended to develop a robotic spacecraft to visit a large near-Earth asteroid and collect a multi-ton boulder from its surface. As the mission engineer, Farah planned operations activities, prepared the mission plan and performed associated resource analyses.

Then came the big one – the Mars Perseverance rover and the Mars Helicopter, Ingenuity, which hitched a ride with the Perseverance rover and successfully demonstrated powered flight on Mars in April 2021. This is the first such flight in any world beyond Earth – and Farah was part of the team that helped make it happen.

Working on Perseverance was a dream of mine coming true after more than eight years. I have to admit that Ingenuity has a special place in my heart for two reasons: firstly, it was our 'Wright brothers moment', the first powered flight on another planet. Secondly, having done my Master's in the turbomachinery and aerodynamics side of Aerospace Engineering, followed by my PhD in Space Systems Engineering, it felt like I was bringing those two separate parts of my education together in one mission.

That first flight by Ingenuity on 19 April 2021 was truly historic. I remember waking up in the middle of the night to head to the lab to wait for the data to arrive (I am not sure that I even slept). However, what sealed the deal for me was seeing that first black-and-white image that came down from the helicopter navigation camera of Ingenuity's shadow on the surface of Mars. It was taken while Ingenuity was in-flight. Everything about that day was extraordinary; a picture-perfect flight, incredible imagery and a video taken by the rover with just the right timing to capture the entire thing. I think part of what we accomplished is still sinking in for me, even all these months later, and I am sure that I will always remember that incredible day.

I was in charge of coordinating the deployment of Ingenuity from the belly of the Perseverance rover down to the ground. I also coordinated all of the rover activities associated with the first flight. My big scary moment was not the day of that first flight however, but earlier, on 4 April 2021, when we dropped the helicopter on the surface of Mars. My team and I had spent hundreds of hours preparing for that complex set of events and I can still remember seeing that first image of the helicopter safely on the ground after the rover drove away from it. Better yet, we heard from it straight away on that first day and then again the next morning, when we confirmed that it had survived the harsh Martian night.

The importance of staying curious

What is your advice to others interested in following a similar route to you?

I would say dive in head-first and follow that curiosity. Information is readily available now more than ever, so if you are curious about a particular field, learn as much as you can about it and push yourself! Any career path that you follow will come with hurdles and failures, but having a goal that you are passionate about is what helps you to pick yourself up when those failures happen and try again.

What's next for you? Any new projects in the pipeline or goals yet to be fulfilled?

There are so many incredible opportunities; all I know is that I will keep exploring. The JPL has a variety of ongoing projects to explore other planets, moons and asteroids, and even to learn about the origins of the Universe or search for exoplanets. But for now, I am taking time off to focus on some personal projects and then…we will see!

> "At the Jet Propulsion Laboratory, I get to travel to other worlds through the eyes (cameras) and ears (microphones) of the robots that we send out there. Sometimes, I still pinch myself!
>
> Farah Alibay

↓ Farah next to a mock-up of the Ingenuity helicopter on 19 April 2021, the day of the first helicopter flight on Mars

Image courtesy of Farah Alibay

Solar batteries without the charger? We're working on that

Credit: Adobe Stock

Professor Michael De Volder tells us how a Friday afternoon experiment led to research on a new low-cost battery design that can be charged directly by light without a separate solar cell or power converter.

How does what you're working on differ from conventional batteries?

For most of us, recharging a battery is easy. When a battery is flat, you plug it into a charger and after an hour or so you are good to go. But in a remote area, without access to mains electricity, this becomes much more complicated.

You can of course use solar power to charge batteries in off-grid locations, but this always requires a separate solar cell and a power converter, in addition to the battery, which makes solar charging systems more expensive and less robust.

What we have developed is a way to charge the battery directly from sunlight — no separate solar cell, no power converter. So we've reduced those three components to just one, a battery that can be exposed directly to light and recharges all by itself, without any external intervention.

We're also using a cost effective battery chemistry relying on zinc-ions rather than lithium-Ions, so we believe that it will be possible to have the light-charging capability for the cost of a normal battery.

You've said that this is a proof-of-concept and that further testing is needed. But what are some of the applications that you envision?

This technology is still in its very early days. One problem we have to solve is increasing our efficiency in converting energy from sunlight to energy stored in the battery. Conventional solar cells have an energy conversion efficiency of 10–20%, whereas the efficiency of our battery is still only 1%. We are working on improving this, but in the near future this technology mostly has applications in situations where the energy conversion efficiency isn't the most important criterion, as compared to the price or volume.

If we think of technologies such as the sensors that are used in smart cities that are distributed over large areas and not connected to mains power supplies, those are sometimes exposed to the sun for many hours a day but consume very small amounts of energy. Therefore, you don't need a very high energy conversion system, but having a compact energy solution is important.

For parts of the world where people are trying to fight energy poverty, having a system that is able to harvest sunlight and store its energy cost-effectively would be extremely useful. Where cost and safety might be more important considerations than energy conversion efficiency, this technology is promising.

You're still working on conversion efficiency, but have you made progress in other areas?

One area we have made clear progress in is improving the stability of the batteries as they are charged and discharged, bringing it closer to what you would expect from a commercially available battery.

We've now published a couple of papers on this topic. Back when we first reported on it, we were using a class of materials for the batteries called perovskites, which are used in photovoltaics quite often because they can achieve high efficiencies in energy conversions. But when we made those batteries, after about 5 to 10 charge-discharge cycles, the battery would be dead. That's obviously not great, and since then we have started using various metal oxide materials as active material, and with those we can hit hundreds of charge-discharge cycles with negligible capacity loss. Importantly, we have only tested our batteries in labs with solar simulators. We haven't done any field trials, deploying the batteries in real situations where exposing them to the sun and hot environments might degrade the device performance.

What is the next step?

In addition to increasing the number of charge-recharge cycles and the charging efficiency, we also want to improve the output voltages. The initial batteries we produced were limited to one volt, so we are working hard on how to get that up. To date, the development of our materials has mainly come from the battery angle. In our group, we mainly work on batteries and not so much on photovoltaics. And the design of our devices so far is built very much on our understanding of batteries and very little on the process of converting light into energy. I think there is a lot of improvement possible simply in adopting design principles from photovoltaics — these have not been fully explored in our devices, so that's where we think we can increase the efficiency the most.

Dr Buddha Deka Boruah, Dr Shahab Ahmad, Angus Mathieson, Lifu Tan and Arvind Pujari contributed to this work.

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Act now to ensure buildings are net zero carbon and adaptable to a changing climate

Credit: Manpeppe – stock.adobe.com

To ensure that the built environment is equipped to withstand climate change, integrated frameworks are needed at the design phase to enable net zero adaptation, say researchers.

A review of recently updated building sustainability assessment tools, BREEAM (UK), Green Star (Australia) and LEED (USA), found that significantly less weighting is given towards the integration of climate change adaptation – tools which investors use to reduce their exposure to climate risks within their developments. Although these assessment tools are not official standards, they may be specified or mandated by clients and local planning departments, as they are reflective of best practice measures adopted by the industry. The findings are reported in the journal *Environmental Research: Infrastructure and Sustainability.*

The publication of the review, carried out by PhD student Amie Shuttleworth and Dr Kristen MacAskill, came at a critical time ahead of the United Nations COP26 Climate Change Summit, which was held in Glasgow last year, providing an opportunity to ensure that adaptation considerations increasingly become a part of the climate change action agenda.

"Currently, there is no widely adopted system for assessing building adaptation in design, and clearer guidance is needed," said Amie. "There has been plenty of focus on climate mitigation efforts through research and policy, but less on climate change adaptation, even though they are clearly related concerns. If adaptation is not adequately considered, we will remain in a situation where buildings designed today will likely need upgrades within their lifetime, leading to a range of ramifications, including retrofit costs and performance-related issues, which could, in extreme cases, render some buildings unsafe."

A review of BREEAM, Green Star and LEED revealed that emphasis on action pertaining to climate issues is heavily weighted towards mitigation, whereas the integration of adaptation considerations is much lower and in most cases not mandatory.

"This makes it challenging for investors to know whether climate risks have been assessed and acted upon within the development, even if the highest 'sustainability' rating is awarded," said Amie.

Of the three assessment tools, BREEAM (UK) was found to have the most advanced integration of both mitigation and adaptation considerations, with future climate change integrated into a number of key credits (asset score points), such as thermal comfort and water use. It also has a standalone credit recognising the multifaceted impact climate change has on the core design process. However, future climate change is not stipulated to be included as part of the 'reduction of energy use and carbon emissions' credit, nor is it mandatory to conduct a future climate change impact scenario review.

"This is an important aspect to consider when designing a net zero carbon building, particularly with regards to the impact of temperature increases on a building's performance," said Amie.

In comparison, the researchers found that a minimum requirement of Green Star (Australia) rated buildings is to have a pre-screening assessment to identify climate-related risks facing that building, in order for it to be determined 'sustainable'.

"This push on adaptation, alongside mitigation of emissions, is an important step forward for the industry," said Amie. "However, there is still the possibility that climate change adaptation will not be integrated into the design, as a developer can choose not to act on the results of the risk assessment. This is an area that BREEAM is more prescriptive in requiring throughout."

A review of LEED (USA) meanwhile, found just one aspect that directly relates to climate adaptation – whether the development is in an area at high risk of flooding.

Summing up, Amie said that in order to achieve the ultimate desired outcome to ensure buildings are both net zero carbon and adaptable to a changing climate, greater transparency is needed to show *how* climate change has been considered.

"In order for adaptation considerations to be operationalised within the engineering and construction industry, better mechanisms for achieving the integration of mitigation and adaptation are required. As our perspective paper has demonstrated, there is still some way to go. What is needed is further development in standards, moving from voluntary to mandatory, at a time when climate change is already happening and negatively impacting the built environment and those who use it."

This research was funded by the UK Engineering and Physical Sciences Research Council, Doctoral Training Studentship.

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→ From left, Umang Bhatt, Scott Jeen and Joshua Nevin

Turing Enrichment Scheme at The Alan Turing Institute

PhD students Umang Bhatt, Scott Jeen and Joshua Nevin have been accepted into the Turing Enrichment Scheme.

The Alan Turing Institute is the UK's national institute for data science and artificial intelligence (AI). The Turing Enrichment Scheme offers students currently enrolled on a doctoral programme at a UK university the opportunity to join The Alan Turing Institute for up to 12 months, where they can continue their PhDs while enriching their research and making new inter-institution collaborations.

Umang's research interests broadly lie in statistical machine learning, explainable AI, and human-machine collaboration. He is currently studying how transparency affects the formation of a successful and productive human-machine partnership. Specifically, he is concerned with the role of explanation and uncertainty in facilitating interaction between machine learning models and human decision makers. During his Enrichment Scheme, Umang looks forward to collaborating with the Safe and Ethical AI programme on problems related to the fairness, transparency and robustness of AI systems. He plans to leverage the Institute's expertise in public policy to augment his machine learning transparency research and to forge connections with domain experts and regulators.

Umang said: "I am primarily interested in trustworthy machine learning. Encompassing explanation, documentation and disclosure, transparency is key to displaying the competence of machine learning models to experts in healthcare and criminal justice. I study how algorithmic transparency affects human decision-making."

In 2020, Umang was appointed a Fellow at the Mozilla Foundation. Umang is one of two PhD students in a cohort of 29 individuals selected from 14 countries to work on building a more trustworthy Internet. Mozilla Fellows are web activists, open-source researchers and scientists, engineers and technology policy experts, who work on the front lines of ensuring technology remains a force for good. As a Mozilla Fellow, Umang has been understanding the transparency needs of stakeholders affected by AI systems and developing methods to generate diverse example-based explanations from AI systems. By coupling advocacy at a civil society like Mozilla with the technical nature of a PhD, Umang can translate how algorithms for creating safe AI systems implicate practical considerations for policy makers and practitioners.

Scott's research is in Reinforcement Learning (RL), a subfield of AI, where he designs agents that learn to reduce emissions from energy-intensive industrial processes autonomously. He is working with Emerson Electric, a US Fortune 500 company and operator of 10,000 cold storage facilities in North America. Together, they use cold-store facility data to make predictions of future occupancy, weather, produce-levels, and grid carbon intensities that inform energy-efficient control policies. Such techniques have been shown to improve datacentre energy efficiency by 30% in simulations, but have seen little exploration in further settings or *in situ*.

During his placement on the Enrichment Scheme, Scott plans to leverage the Institute's expertise in RL to design algorithms that operate well when data is scarce, as is common in most real-world settings. He will also take advantage of the Institute's cloud computing infrastructure to test the scalability of these agents to many varied settings where emission reduction would be valuable.

Scott is interested in machine intelligence and its capacity to help mitigate climate change. In practice, this means writing scalable, probabilistic machine learning algorithms – primarily model-based RL agents – to optimise the control of equipment in buildings and industrial processes. He's particularly interested in an RL agent's ability to take actions that, at first, seem counter-intuitive to humans, but later provide us with a richer understanding of the system than we could have achieved alone.

Joshua summarises his research and plans for the Enrichment Scheme: "My research broadly encompasses explainable machine learning approaches for the design and operation of optical fibre communication systems. Specifically, my interests include the design and application of physics-informed machine learning methods, the intersection of explainable machine learning and RL, approaches for digital twins in optical networks and the design of machine learning algorithms for situations where data availability is strongly constrained.

"I am currently investigating how Gaussian processes can be used to estimate the performance of deployed optical network components, from a constrained volume of monitoring data, for applications in digital twins.

"During the Enrichment Scheme, I plan to use the world-class expertise that the Institute has to offer, particularly in the data-centric programme. I am looking forward to engaging in new collaborations and delivering explainable data-driven methods that leverage knowledge of system physics."

www.turing.ac.uk

Design Tripos brings arts and science together in one degree to address global challenges

A brand-new Cambridge degree – the first undergraduate course 'designed from scratch' at the University for a number of years – will merge arts and science to address some of the world's most pressing challenges.

For the first time, the Design Tripos brings together architecture, engineering and materials science in a single degree. Blending technical content with design freedom, the course will offer a different kind of creativity, and a new approach to tackling societal and environmental issues, including poverty and climate action.

Using practices of design and our understanding of how they influence people, economies and the natural world, the four-year Master of Design (MDes) degree will be structured around hands-on, problem-based learning projects. Studio work and practical skills, including drawing, writing, coding, and fabricating, will complement taught courses in the humanities, social and natural sciences, and mathematics – bringing historical, cultural, ecological and economic context.

The Design Tripos – which will start in October 2024, and lead to a Master of Design (MDes) upon successful completion – has been developed by the Department of Architecture in collaboration with the Departments of Engineering and Materials Science & Metallurgy, amid a growing desire among students in these fields to blend elements of each other's subjects.

"It's pioneering – we're merging the arts and sciences under the umbrella of creativity and design, and constructing the course to be as open and interesting as possible," said Professor Michael Ramage, Director of Cambridge's Centre for Natural Material Innovation and Deputy Head of the University's Department of Architecture. "We don't know of any other single degree course that brings these three subjects together like this."

Delivering clean growth and a circular economy requires not just specific technical expertise but a holistic understanding of the world, said Professor Ramage, who points at the COVID pandemic response as an illustration of how rapid solutions arise from the confluence of different fields.

"Pressing challenges – such as achieving net zero greenhouse gas emissions by 2050, and reaching sustainable development for all – are likely to be addressed directly as design challenges, rather than as separate mathematical or engineering challenges," he said. "They don't fit into a neat academic box; unlocking creativity requires collaboration and knowledge across a variety of disciplines."

He added: "We know there is general interest among students to apply their education to global grand challenges, and particularly sustainability challenges, which can be met through design. But it's very hard to study across disciplines – there's no way you can create a degree like this simply by taking classes from those three different departments, which are all in three different Schools at the University. That's why we've had to design the degree from scratch."

The blended nature of the Design Tripos will appeal to a wide range of students, and aims to help address gender disparity in design fields. Over the past three years, fewer than 40% of applications to Engineering and Physical Sciences at Cambridge have been from female students.

Professor Graham Virgo, Senior Pro-Vice-Chancellor for Education, said: "The Design Tripos will teach both the 'know-how' and the 'know-what' to help develop the next generation of pioneers and leaders in industry, public service and society. The course is aimed at students who are thinking about global problems and want to learn how they can do something to help. We also know that employers are increasingly looking for multidisciplinary knowledge and team-working skills, and so the Design Tripos also anticipates the hybrid jobs of the future."

Cambridge researchers elected Fellows of the Royal Academy of Engineering

Three researchers from the Department of Engineering are among the leading figures in the field of engineering and technology elected as Fellows of the Royal Academy of Engineering.

Professors Holger Babinsky, Andrea Ferrari and Rob Miller (pictured left to right) have been elected in last year's intake, which consists of 60 Fellows, four International Fellows and five Honorary Fellows. Each individual has made exceptional contributions to their sectors in their own way, as innovation leaders, inspiring role models, or through remarkable achievements in business or academia.

Professor Holger Babinsky is Professor of Aerodynamics and a Fellow of Magdalene College. He researches fundamental and applied aerodynamics with application to aeronautics, road vehicles and energy production.

"I am delighted to receive this remarkable honour and feel very lucky to be recognised by my peers for doing something I love," said Professor Babinsky. "I am also truly grateful to the University, the Department of Engineering and all my colleagues and students for providing the environment and support that allowed me to grow as a researcher and educator."

Professor Andrea Ferrari is Professor of Nanotechnology. He is Director of the Cambridge Graphene Centre and of the EPSRC Centre for Doctoral Training in Graphene Technology, and a Fellow of Pembroke College.

"The Cambridge Graphene Centre allows our partners to meet, and effectively establish joint industrial-academic activities to promote innovative and adventurous research with an emphasis on applications," said Professor Ferrari. "It is often at the interface between academia and industry that new challenges for fundamental research are generated. I am pleased the Royal Academy of Engineering has recognised the translational potential of our work and I see this as a further encouragement to develop state of the art facilities that will lead to world-class research, technology and innovation."

Professor Rob Miller is Professor of Aerothermal Technology. He is Director of the Whittle Laboratory and a Fellow of Gonville and Caius College. Much of the research of the Whittle Laboratory is geared toward solving one of technology's biggest puzzles: how to achieve zero-carbon flight.

"I am deeply grateful to all the colleagues and students that I have worked with, especially at the Whittle Laboratory and at Rolls-Royce, without whose support this would not have been possible," said Professor Miller. "Throughout my career I have benefited from working closely with industry. I believe that it is only through these partnerships, between industry and academia, that engineers can meet society's greatest challenge: climate change."

First Chief Scientist of The Alan Turing Institute

Professor Mark Girolami has been announced as The Alan Turing Institute's first Chief Scientist, responsible for the creation and delivery of the Institute's scientific and innovation strategy, as well as its approach to ethics and responsible innovation.

The appointment of Professor Girolami to the newly-created role comes at a critical moment for UK science and technology, in particular AI and data science, following the UK government's first-ever National AI Strategy, launched recently with a new 10-year plan to make the UK a global AI superpower.

Professor Girolami is the Sir Kirby Laing Professor of Civil Engineering at Cambridge, where he also holds the Royal Academy of Engineering Research Chair in Data-Centric Engineering (DCE) and is an Academic Director for the Cambridge Centre for Smart Infrastructure and Construction (CSIC).

"I am delighted to have this opportunity to become the Turing's first Chief Scientist and, in this role, provide the required leadership to accomplish the Institute's mission of making great leaps in data science and AI research and innovation in order to change the world for the better," he said. "In setting the strategic direction for the Institute, we will provide a model of how safe and ethical data science and AI can build long-term strengths and benefits for society and the economy, and support the UK's needs and broader ambition to be a global leader in this space. Linked to this will be our research approach to equality, diversity and inclusion (EDI) – a key part of the Turing's new EDI strategy."

ALUMNI UPDATE

Meet the assistant civil engineer helping to build a better world

Alumna Micheala Chan was named as one of the Institution of Civil Engineers (ICE) President's Future Leaders for 2020/21. As part of the programme, Micheala – who is driven by a desire to help improve the quality of life of others – drew attention to the issues of sanitation, access to clean water and future energy needs.

"Access to clean water and sanitation are key issues that we don't talk about enough," says Micheala, one of six young engineers recruited by ICE President Rachel Skinner. The cohort spent a year working on projects assigned to them to help drive forward the ICE President's agenda with a focus on a carbon net-zero future.

"Sanitation, in particular, is a crucial element to global health and yet it often suffers from political neglect, given that water is often more politically expedient and favourable. I wanted to bring a much-needed focus on sanitation, to highlight that the real challenges we face in global access are delivery and access (as opposed to fancy technical solutions) and to bring attention to the intersections between Sustainable Development Goal 6 – ensuring availability and sustainable management of water and sanitation for all – and other exacerbating factors."

"It is time for the civil engineering industry to push the boundaries with respect to climate change," she added.

Micheala, who studied a Master of Engineering (MEng) at Cambridge, is an assistant civil engineer at Arcadis, a global design and consulting company. She leads on civil engineering design across a number of projects, liaising with stakeholders on cost, programmes and designs. Her main responsibilities include preparation of outline and detailed design packages. She is currently working on Thames Water Developer Services projects, involving pipeline design, and Thames Water Asset Protection, reviewing impact assessments for a number of new developments.

Here she helps bust some myths about civil engineering, shares valuable advice and reminisces about her top Cambridge moments:

Many people believe that civil engineering is all about calculations and building bridges. I believe that times are changing and the civil engineering industry has felt the onus to change its approach to our jobs.

Civil engineers have a moral imperative to consider social factors and big-picture considerations, not just technical (for example, designing for inclusivity and equity) and we are really starting to see that come out in certain sectors and projects.

My advice for budding engineers is to pursue your passions and what challenges you, and if you are doing what you love, this will keep you going when the going gets tough. Keep your eyes open and stay curious; inspiration is everywhere. Be confident and keep trying.

Working with the Cambridge Development Initiative was the ultimate highlight of my time at Cambridge. I learned a lot from my experience helping to run a non-governmental organisation (NGO) working in international development in Tanzania, particularly with regards to the role that engineers can play in improving quality of life and the wider ethical implications of our work. It also gave me the chance to use my skills to push boundaries towards achieving Sustainable Development Goal 6.

Internships provided me with an amazing opportunity to apply the knowledge I was learning in the lecture theatre to real-world experience. Internships also build your professional network and give you increased visibility in the field. With a general engineering degree like the one at Cambridge, internships give you the opportunity to explore various career paths to find out what you enjoy.

Without perspectives from people with different backgrounds, engineers are destined to see problems through a single lens. This will not be resolved without creating systemic change to level the playing field for women and minorities. I have often felt imposter syndrome when given a seat at the table, but I have also been reminded, by the many amazing women around me, that my voice and what I have to say matters, and so does yours!

As well as raising awareness of big issues such as climate equity, in the future I hope to work on projects in Water, Sanitation and Hygiene (WASH) to improve equitable access globally. I would like to change the mindset of engineers, to encourage the industry to demonstrate its social awareness and ability to break silos to deliver sustainable and human-centred results for people. I try to live by the African American novelist Toni Morrison's quote, "Your real job is that if you are free, you need to free somebody else. If you have some power, then your job is to empower somebody else."

Business model innovation is key to beating COVID-19 debt

New business models are essential to unlocking the economic growth potential of digital technologies, and offer a way out of rising debt-to-GDP ratios.

By Chander Velu and Yifeng (Philip) Chen

The measures taken to support economies battered by COVID lockdowns helped to prevent immediate economic collapse, but have drastically increased the ratio of national debt to GDP, and will eventually have to be paid for. We argue that debt-to-GDP ratios can be reduced to manageable levels by focusing on business model innovation that leverages cutting-edge digital technologies that are emerging, but which have yet to become widely adopted.

Artificial intelligence (AI), 5G connectivity, cloud computing, and 3D printing, when combined with appropriate business models, could spur faster productivity and economic growth, lowering the debt-to-GDP ratio as a result. The technologies themselves are necessary but not sufficient.

Technology-led research and development is often pointed to as an underlying driver of economic growth, but attributing all productivity gains to R&D greatly simplifies the story. In technological revolutions throughout recent history, there has often been a lag between the introduction of technology and its effect on productivity.

In information and communications technology, though the ‘computer age’ could be said to have begun in the 1970s, it took until two decades later for long-expected productivity growth to begin to materialise, as personal computers fuelled the spread of more generic software that was customisable to a greater number of business contexts. It is only when the technology spreads that benefits are felt across the entire economy.

Today, the combination of technologies like additive manufacturing, distributed ledgers and sensors have the potential for wholesale disruption of the conventional manufacturing, by manufacturing things closer to the consumer. But realising this potential requires a transition to new business models.

Transitions like this involve a lot of experimentation in the application of new technologies. Taking the US as a reference, if the combination of new digital technology and business models results in productivity growth increasing from the current projected 1% per annum to 3.5%, this would reduce the US debt-to-GDP ratio to the pre-pandemic level of around 80% by 2045. By contrast, the ratio will significantly expand if productivity growth remains at 1%.

In light of this potential for business model innovation to unlock growth, governments in developed economies should consider various policy initiatives to accelerate its development.

Subsidies and grants, not only for these new digital technologies but also for their business applications, are a good first step. Governments should consider subsidising firms that have, or have plans to implement, organisational and business model changes designed specifically to complement their technological assets.

Tax schemes can go even further and subsidise changes that take place between firms in order to encourage business model innovation across the industrial ecosystem. Firms could jointly apply for finance if they alter their current interactions with other firms in response to their technologies. This would encourage firm coordination not just within but across entire industries.

Governments could also permit tax rebates if firms are able to demonstrate productivity improvements via independent audits. Although firms clearly have an incentive to improve productivity, the incentive may not be sufficiently strong for two reasons.

First, productivity, as conventionally defined via accounting principles, is rarely measured directly by firms and does not drive their day-to-day decisions. Second, firms are ultimately motivated by profit, and profitability can be achieved not only via productivity improvement but also through appropriating a greater proportion of value from competitors and consumers.

Arguably, the latter approach is often relatively easier to achieve than productivity increases, aggravated by a lack of competition in many markets. With tax rebates, for example, set to a given proportion of productivity increase, the financial incentives for improving objectively measurable productivity would become stronger.

Governments should also provide relevant training centred specifically around transformational opportunities provided by the next generation of digital technologies. Skills shortages in scientific, technology, engineering, and mathematics (STEM) areas have been identified as a bottleneck to technologically driven business model innovation. Governments could seek to encourage the emergence of common standards across the industrial chain, aiming to encourage greater cross-firm and cross-industry collaboration. This should begin with the legal framework being redesigned, as it is currently inadequately equipped to address the concerns of emerging technological use. Governments should consider adopting a much nimbler legal framework for use exclusively in technological and business-model-related matters. Such a legal framework must also respond rapidly to any international technical standards that emerge.

Historically, new technologies have not immediately contributed to productivity growth. Only when complementarity was established between the new technology and innovative business models was major productivity growth realised. As we enter a race against huge debt and interest payments in the wake of COVID-19, economic policy should be focused on encouraging this development for the next generation of digital technologies.

→ Apartment building under construction

Credit: diesirae – stock.adobe.com

Cambridge Enterprise invests in tech start-up aiming to cut CO_2 emissions by gigatonnes

The investment will accelerate the development of AI technology start-up Carbon Re to help the global cement industry and other energy-intensive industries reach net zero targets.

The University of Cambridge Enterprise Fund has joined in a £1 million investment in Carbon Re, a UK climate tech start-up that uses artificial intelligence to cut CO_2 emissions in the global cement industry and other hard-to-abate industrial processes.

Carbon Re combines world-class deep reinforcement learning – a field of artificial intelligence best suited to managing complex decision-making – and industrial sustainability expertise from the University of Cambridge’s Institute for Manufacturing (IfM), part of the Department of Engineering, and UCL’s Energy Institute.

Carbon Re’s cloud-based platform, Delta Zero, uses powerful AI tools to achieve operational efficiencies in energy intensive industries, such as cement production, reducing operational costs and carbon emissions to otherwise unachievable levels. Delta Zero enables immediate reductions in energy consumption, cost and carbon emissions, with no capital expenditure.

Carbon Re is currently running pilot projects at cement plants in the EU, Turkey, India, Thailand, and Vietnam. Studies indicate that the Delta Zero platform could save a single cement plant US$2.3–5.9 million per annum and provide a 20% reduction in CO_2 emissions from fuel.

Using AI to analyse a customer’s manufacturing data, Carbon Re recommends ways to cut emissions during cement production by modelling the production environment and dynamically identifying the optimal process for the lowest possible carbon dioxide output and fuel use.

Currently the cement industry is Carbon Re’s primary area of focus, but the company plans to expand into other energy intensive industries, including steel and glass, over the next 12-18 months.

The investment is co-led by the Clean Growth Fund, the UK venture capital fund; the UCL Technology Fund and UCL Business Ltd’s Portico Ventures; and Blue Impact Ventures.

Sherif Elsayed-Ali, CEO of Carbon Re, said: “Our mission is to reduce global emissions at the gigatonne scale, starting with the cement industry, and to become the leading global AI company to deliver industrial decarbonisation.

“Energy intensive industries, such as cement, steel and chemicals, are vital to the global economy, producing 75% of all the material in the manufacturing and construction sectors. They also represent more than 20% of global greenhouse gas emissions. Our advanced software helps these industries cut their energy costs and, crucially, reduce their carbon emissions. Carbon Re’s AI technology provides heavy industry with an effective solution to address their critical challenges of energy costs and emissions reduction.

“The road to a zero-carbon world will be long but with the support of the Clean Growth Fund and our other investors, our AI products and solutions will evolve to accelerate the transition of energy intensive industries.”

Stephen Price, Clean Growth Fund’s Investment Director, said: “We are all really excited about Carbon Re’s ability to make a huge and positive impact across the world. The pressure is on the hard-to-abate heavy industries, like cement, to cut their emissions and to do so much faster if Net Zero is to be achieved. By applying Carbon Re’s leading edge AI technology, heavy industry’s transition to more sustainable practices can be accelerated.”

Chris Gibbs, Investment Manager, Cambridge Enterprise, said: “Energy intensive industries, like cement, are among the hardest sectors to decarbonise. Carbon Re has a great team and a great technology that can be deployed today to save millions in energy and greenhouse gas emissions. Two prestigious UK universities, the University of Cambridge and UCL, alongside a tremendous group of investors are pleased to back an outstanding business that will bring real value to industry and real value to the planet too.”

> “Energy intensive industries, like cement, are among the hardest sectors to decarbonise. Carbon Re has a great team and a great technology that can be deployed today to save millions in energy and greenhouse gas emissions.
>
> Chris Gibbs, Cambridge Enterprise

ifm.eng.cam.ac.uk

Funding awarded to harness the power of machine learning in healthcare and safety-critical applications

PhD student James Allingham has been awarded $40,000 in funding to support his machine learning research project with the potential to positively affect health-related or safety-critical applications, such as cancer diagnosis or automated driving, where computational resources are limited.

The Qualcomm Innovation Fellowship Europe programme rewards young researchers in the fields of artificial intelligence and cybersecurity with individual funding, dedicated mentors from the Qualcomm Technologies team, and the opportunity to present their work in person to an audience of technical leaders at the company's HQ in San Diego.

James, who is supervised by Dr José Miguel Hernández-Lobato in the Department's Machine Learning Group, was selected for his proposal titled *Diversity-encouraging Priors for Cheap but Well-calibrated Uncertainty in Deep Learning*.

Standard deep neural networks are used very successfully in many applications, from virtual assistants to self-driving cars, but these networks are often overconfident and remain unable to robustly and reliably quantify uncertainty in their predictions. Existing solutions for uncertainty quantification require strong approximations and significant computational resources, but there is room for improvement regarding the accuracy and the calibration of the results.

James proposes a method that encourages diversity among the predictions made by a model. By making a number of diverse predictions, a model is less likely to be overconfident, and more able to make accurate predictions. James also plans to release an open-source library for training and deploying the resulting models.

"I don't always know whether I am going down the rabbit hole of curiosity or working on problems that actually matter – receiving the fellowship tells me that it is the latter, which is a big motivation," he said. "It was also a great boost to my self-confidence to be selected as one of the winners, when many fantastic applicants were also working on important problems."

James added: "My ultimate career goal is to apply machine learning to solving climate change related problems, such as weather prediction, to allow for better planning for renewable energy production. In the shorter term, I hope to make concrete contributions to the field of machine learning, with a particular focus on uncertainty estimation and robustness."

Dr Hernández-Lobato said: "James's contributions will enable fast and reliable uncertainty estimation when making accurate predictions with neural networks. The impact of these methods will be broad across a wide range of disciplines that require fast and robust decision-making, for example in self-driving cars, robot control or medical image analysis."

Jim Thompson, chief technology officer, Qualcomm Technologies, Inc., said: "We are proud to see the next generation of inventors bring their work to fruition. The machine learning and cybersecurity solutions they propose can have a significant positive impact on society. Through the Qualcomm Innovation Fellowship programme, we aim to break down some of the barriers that researchers encounter by providing funding and fostering collaboration."

> My ultimate career goal is to apply machine learning to solving climate change related problems, but in the shorter term, I will focus on uncertainty estimation and robustness.
>
> James Allingham

cbl-cambridge.org/people/jua23

Honours, awards and prizes

2021 IEEE Fellow

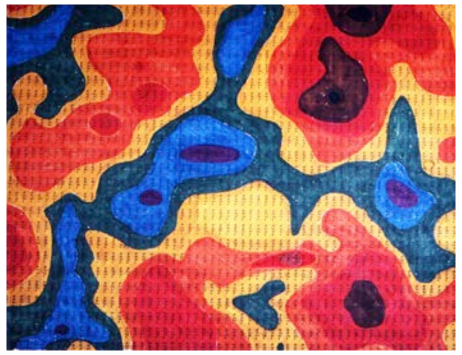
Professor Ashwin A. Seshia has been named an IEEE Fellow for contributions to resonant-based inertial and mode-localised sensors.

Ashwin previously received the 2018 IEEE Sensors Technical Achievement Award (Advanced Career) "for pioneering contributions to resonant microsystems with application to sub-surface density contrast imaging and energy harvesting systems".

IEEE Fellow is a distinction reserved for select IEEE members whose extraordinary accomplishments in any of the IEEE fields of interest are deemed fitting of this prestigious grade elevation.

Tribology Gold Medal

Emeritus Reader Dr Jim Greenwood has received The Tribology Gold Medal from the Institution of Mechanical Engineers, considered the world's premier award in tribology.



↑ A contour map of the roughness on a flat aluminium surface by bead-blasting, constructed from a sequence of parallel traverses by a profilometer, from 1964 when Jim was pioneering digitising surfaces

Dr Greenwood's published work has had an enormous influence on the development of the understanding of some of the most important building blocks of tribology at a fundamental scale.

Tribology is the science and technology of friction, wear and lubrication. Although the study of friction, lubrication and wear in machines dates back at least as far as Leonardo da Vinci's remarkable contributions in the 15th century, it is only 55 years since a single word, 'tribology', was coined to describe this broad field of knowledge. Even now, just over half a century later, that term is still not widely known, nor is it generally recognised as a key enabling technology.

Student-Led Teaching Awards

Janet Lees, Professor of Civil Engineering, and Dr Jagjit Singh Srai, Director of Research at the Institute for Manufacturing (IfM), have received Student-Led Teaching Awards, hosted annually by the Cambridge Students' Union.

Professor Lees won the Best Lecturer Award. Her nominator, student Isobel Sayer, described Professor Lees as someone who had "gone out of their way to combine the best parts of in-person and online lectures. From going to the extra effort to film their lectures in a real lecture theatre to including demonstrations that we could try out at home, they have truly gone above and beyond to make their course incredibly interesting and clear in these strange times".

Dr Srai won the Working in Partnership with Students Award. His nominator, student Kiran Singh Jolly, described Dr Srai as "a beacon of support to all the students he interacts with. This has been especially true this past year, when COVID-19 has affected our lives all too much. He's always been very proactive in providing pastoral support. He is also very involved in running the local Gurdwara, the Sikh centre of worship, where we were all first introduced to him. It's through his ongoing support that over the last few years the Sikh society and the Gurdwara have been able to run events to give back to the community, such as feeding the homeless and working with schools".

↑ Jana and Chawit

COVID-19 impact fund

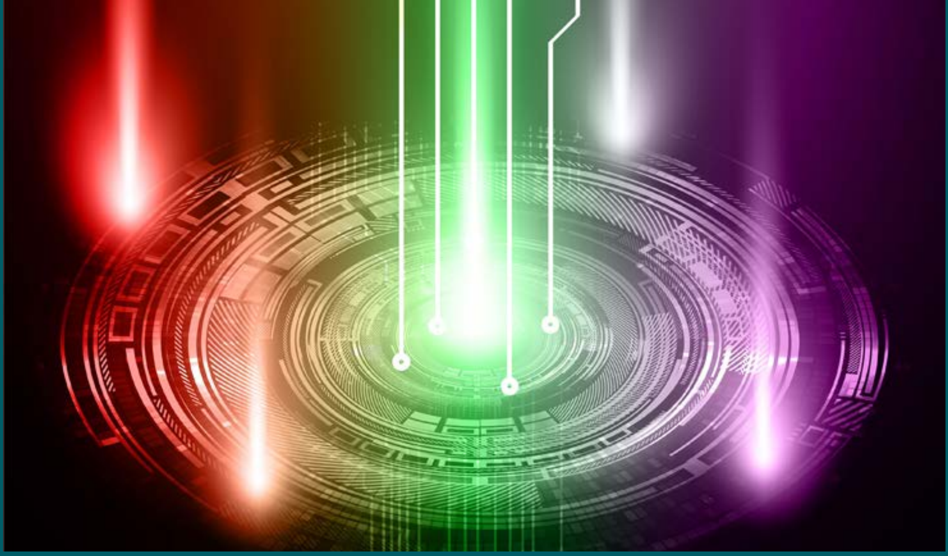
PhD students have been awarded grants in support of their research projects that were hit by delays due to the COVID-19 pandemic.

Thanks to the Rank Prize funding, the 'Return to Research' grants enabled Jana Skirnewskaja, Jamie Lake and Chawit Uswachoke to purchase new equipment. Jana was able to secure microlenses and lenticular arrays to support the creation of augmented reality holograms for head-up displays in cars, and Jamie was able to procure electrical test and measurement equipment vital to the type of experiments he is involved in. Chawit, meanwhile, hopes to use the funding to pursue research in the design of flexible optoelectronic devices based on vertical semiconductor nanowires.

Gates Cambridge Scholarship

Since completing his Master of Engineering degree specialising in Information Engineering, Yassir Fathullah has returned to Cambridge, a recipient of a Gates Cambridge Scholarship, to study for a PhD. Speaking about his journey thus far, he says: "Since a young age, I have been motivated to obtain the best possible education, especially in science and math. My parents are Iraqi refugees who knew, from the moment they arrived in Sweden, that education would be the most important thing, from learning the language to obtaining a university degree."

INSPIRE project to lead a revolution in photonic integrated circuits



Credit: titima157 – stock.adobe.com

The H2020-funded INSPIRE project is leading a revolution in photonic integrated circuits with so-called micro-transfer printing technology and establishment of world-first fabrication platform.

"We are excited to be a part of the H2020 INSPIRE project as we believe it is developing a new technology with the potential to transform the ease of manufacture and scalability of heterogenous integration of photonic integrated circuits," says Professor Richard Penty.

Our access to the internet is made possible by an ensemble of technologies such as photonic integrated circuits (PICs). There is also potential for PIC devices in healthcare or sensing; however their use in these applications is limited by issues with scalability and high-throughput manufacturing.

The Eindhoven University of Technology (TU/e) coordinated H2020-funded project INSPIRE seeks to change how PIC devices are fabricated to make them suitable for applications beyond communications and speed up their large-scale production. INSPIRE has received close to 5 million euros in funding. The University of Cambridge is a consortium partner on the INSPIRE project.

The technological world is built on a foundation of electronic devices. In recent years, though, there has been an upsurge in the use of photonic devices, particularly for data transfer applications. These photonic devices are based on materials like silicon, silicon nitride (SiN) and indium phosphide (InP).

While these devices have the potential for wider impact in other fields like sensors for aircraft or communication devices, their uptake is limited as different materials need to be effectively combined to meet performance requirements.

For example, high-performance fiber sensors used in infrastructure monitoring and microwave signal processing in RADAR systems require both low-noise operation and ultra-low degradation of signals. This can only be achieved through a combination of materials in the manufacturing process. If this manufacturing process can be properly scaled to allow for large-scale production, it is expected that these photonic devices can have a major impact on sensing applications.

INSPIRE is developing wafer-scale micro-transfer printing technologies. Micro-transfer printing devices are first made on a source wafer, after which they are transferred to a target wafer. This printing concept has been established and widely applied by project partner X-Celeprint to different wafers and materials. The INSPIRE project is focusing on the next step: parallel device printing with accurate placement where many integrated devices can be printed at the same time.

The INSPIRE micro-transfer printing technology will be validated for three specific cases: fiber sensors to measure stress, strain, and temperature for use in airplane safety measures; a microwave photonic radio-frequency (RF) pulse generator with application in RADAR and wireless communication; and optical switches for energy-efficient data centers. Compact versions of the III-V opto-electronic components will be developed, enabling designers to use this platform for a wide range of applications.

INSPIRE aims to sustain Europe's industrial leadership in photonics by consolidating established fabrication approaches, such as those from the pioneering pure-play foundry and TU/e spinoff SMART Photonics and the silicon photonics pioneer imec, with the micro-transfer printing technology of X-Celeprint.

This will result in a world-first fabrication platform that combines the strengths of two of the most well-known PIC manufacturing platforms. Methods will chiefly be developed for the coupling of SiN and InP processes, but could also be used for silicon-based photonics.

INSPIRE aims to create a full-function PIC platform, compatible with open-access pilot manufacturing, and with an order of magnitude lower cost for volume production.

INSPIRE's generic approach makes the technology widely applicable and ensures that European innovators can focus their research and development directly on manufacturing platforms. As a result, it should take a shorter time to bring these PIC technologies to market.

The INSPIRE project consortium is made up of TU/e (project coordinator Professor Martijn Heck), imec, Thales, University of Cambridge, X-Celeprint, SMART Photonics, and Amires.

Adapted from an article written by Dr Barry Fitzgerald, Science Communication Officer at Eindhoven University of Technology.

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