THE NATIONAL

ROBOTARIUM

PEOPLE CENTRED :: INTELLIGENCE DRIVEN

ANNUAL REVIEW

2020/21

NATIONALROBOTARIUM

INTRODUCTION

In 2013, David Willets branded Robotics and Autonomous Systems as one of the UK's *Eight Great Technologies* for future growth. In 2019, the global autonomous mobile robots market size was valued at USD 1.9 billion in 2019 and is expected to grow at a compound annual growth rate of 19.6% up to 2027. Since Willets' statement, we have witnessed a flurry of activity and new investment in robotics, including the £4.7 billion Industrial Strategy Challenge Fund (ISCF) from the UK Government which has been complemented by parallel investments from industry, for example, EPSRC's £18.5 million investment in the Offshore Robotics for the Certification of Assets (ORCA) Hub (led by Heriot-Watt University) leveraged £3.5 million support from industry.

Much has been written in recent months about the construction of our world-leading research facility for robotics and artificial intelligence, which will open in early 2022. However, the National Robotarium extends far beyond a physical building and a significant number of projects are already underway. In the body of the report we have presented examples of our success in securing multi-million research programmes from external agencies and creating impact across industries, social care and health.

The National Robotarium draws upon the expertise of highly skilled researchers at the Edinburgh Centre of Robotics (ECR). Created in 2014, the ECR is a bottom-up academic initiative driven by the desire of staff at Heriot-Watt University and the University of Edinburgh to work jointly on projects related to robotics and AI. From its foundation the ECR has developed significant collaborations with partners from across the UK to develop solutions that directly address industry requirements, ensuring that research moves rapidly from the laboratory into the marketplace and society where it can have an immediate application and impact.

The ECR was also the mechanism whereby we secured EPSRC funding to support our Centre for Doctoral Training in Robotics and Autonomous Systems. The award of £6.5M, which when matched with the £11M pledged by industry partners will train 88 PhD students. The focus and enthusiasm of these students will drive much of our research and innovations in future.

Underpinning this is our world-leading training in robotics and AI at undergraduate level through our MEng and BEng programmes in Robotics and our BSc programmes in AI and Informatics. These feed into our postgraduate MSc courses in Robotics and our PhD programme within our Centre for Doctoral Training in Robotics and Autonomous systems. Together, these courses train over 100 undergraduate and 150 postgraduate students each year, fuelling the talent pipeline in robotics.

In future, we aim to expand our offerings to CPD courses, both online and in-person, leveraging technical advancements in cyber-physical systems and telepresence at the National Robotarium.

The National Robotarium also aims to champion STEM activities, inspiring young people in the positive role of robotics and AI, encouraging them to consider a career in the field. Our Education Hub will engage the public regularly through school visits and open days. We know that its youngest visitors and enthusiasts will be the technology creators of the future.

Helen Hastie and Yvan Petillot

OUR VISION

Our vision for the National Robotarium is to be a world-leading centre for robotics and artificial intelligence. Its collaborative approach creates innovative solutions to global challenges. By developing highly skilled visionaries, its pioneering research moves rapidly from laboratory to market - accelerating growth, attracting investment and delivering benefit for society.

OUR STAFF

The body of staff at the National Robotarium includes 68 principal investigators of international standing from 12 cross-disciplinary research groups. A list of all staff within the ECR can be found at **Edinburgh Centre for Robotics**. We are actively recruiting to add to this academic staff complement and are currently in active negotiations with a number of academics and new research fellows who have joined the group recently.

OUR LEADERSHIP TEAM

Professor Helen Hastie
Co-Academic Lead

Professor Helen Hastie leads the UKRI Trustworthy Autonomous Systems (TAS) Node in Trust. This Node is creating a UK research centre of excellence for trust that will inform the design of Autonomous Systems in the future, ensuring that they are widely used and accepted in a variety of applications. It will explore how to best establish, maintain and repair trust by incorporating the subjective view of human trust towards autonomous systems, thus maximising their positive societal and economic benefits.

Managing trust through transparent interaction will increase the confidence of those using autonomous systems, allowing them to be adopted in scenarios never before thought possible. This might include situations that currently endanger humans, such as pandemic-related tasks or those in hazardous environments.

Professor Yvan Petillot
Co-Academic Lead

Professor Yvan Petillot is driving the next generation of remote telepresence robotics solutions to service the offshore renewable sector. With industrial partners including EDF and SeeByte, his team is developing autonomous systems that can inspect and repair wind turbines, sub-structures and energy cables.

These systems are deployed autonomously from shore using autonomous surface vessels or can be deployed permanently on the assets. Over the next three years, an ambitious plan to demonstrate prototype systems offshore will be undertaken, paving the way for large-scale robotic inspection, maintenance and repair of offshore wind farms of the future.

Autonomous and resident robots have the potential to revolutionise how we work in the most extreme environments and contribute positively to our net-zero goals. Deployed offshore, in nuclear plants and in space, they can be supervised by a team of expert operators and analysts from the comfort of remote operation centres, bringing the right expertise to the situation at hand whilst reducing the carbon footprint and cost of remote operations.

OUR LEADERSHIP TEAM

Professor Verena Rieser
Director of Ethics

Professor Rieser and her team give consideration to questions like ‘Can machines generate text which is factually correct?’ and ‘How can algorithms mitigate or counteract bias in the data?’ Her research sits at the intersection of Language Technology and Machine Learning, for interdisciplinary applications including Human-Robot Interaction, Spoken Dialogue Systems, and Natural Language Generation. Dr Rieser’s research explores a different model of smart assistant by asking whether machines can teach themselves how to talk, and the application of machine learning in this context.

Professor Rieser and her team are also working to combat bias in Conversational AI, examining questions like ‘Is it acceptable to abuse an AI?’ and ‘Have gender stereotypes, including abusing female personas without risk of feedback, already become ingrained in our culture?’

With so many members of the public now using these systems in their daily lives, and children hearing how we interact with female AI assistants, is there a risk that they begin to associate this with negative gender stereotypes?

Professor Lynne Baillie
Human-Robot Interaction and social care

Professor Baillie and her team focus on the interaction between humans and technology, and the development and evaluation of novel interactive technologies. Working alongside care organisations and housing associations, Professor Baillie’s interests include health and rehabilitation technologies. She heads up the Assisted Living Lab, exploring technologies to help individuals live independently for longer, with research ranging from robotics and conversational assistants to IoT devices and wireless monitoring techniques.

Her team works closely with the NHS, care homes, housing associations, charities and care organisations to create technology to complement and support existing services and care providers. An example is a collaboration with Chest, Heart, Stroke Scotland. One outcome was that stroke survivors wished to have augmented physical therapy. As a result of this insight, the team started working with physiotherapists at the Astley Ainslie Hospital in Edinburgh to investigate what would be needed to deliver such therapy via a Pepper humanoid robot. The aim is that the Pepper robot will provide additional therapy between formal sessions with a physiotherapist in order to continue the patients’ exercises and track their progress.

Dr Richard Carter
High Precision Manufacturing

As the academic lead for High Precision Manufacturing, Richard's research interests cover high-power laser manufacturing and fibre optics. Recent projects include high power beam delivery with novel hollow core fibre optics, automation of laser manufacturing processes, novel 3D beam shaping, fibre optic environmental sensing, micro material processing including machining, drilling and welding, and microwelding of highly dissimilar materials.

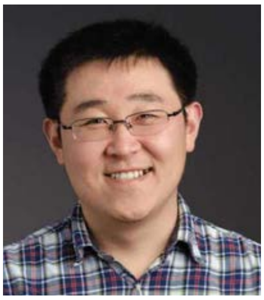
The R&D team is propelling cutting-edge research into laser technologies and applications in the field of manufacturing, with an ambition to reduce the cost of these techniques while increasing reliability, accuracy and precision.

Recent projects include investigating methods of directly welding optical materials to structural materials. In a breakthrough for the manufacturing industry, the team has been successful in welding glass and metal together using an ultrafast laser system. Various optical materials such as quartz, borosilicate glass and even sapphire were all successfully welded to metals like aluminium, titanium and stainless steel using the laser system, which provides very short, picosecond pulses of infrared light in tracks along the materials to fuse them together.

There is a wide range of potential applications for new methods of bonding these materials, including the construction of laser systems, where optics need to be very accurately aligned and then bonded in place. By developing new technologies, the team aims to cast aside the problems that arise from existing technology, such as contamination of optical surfaces and inadequate product lifetime.

The new process could transform the manufacturing sector and have direct applications in the fields of aerospace, defence, optical technology and healthcare. If research can lead to laser manufacturing at lower cost with higher reliability, this would have a knock-on effect for the applications of these lasers. To achieve this goal, the team is now focused on making the process more reliable.

OUR LEADERSHIP TEAM



Dr. Sen Wang
Robotics and Autonomous Systems Lab

Dr. Wang and his team focus on robot perception and autonomy using probabilistic and learning approaches, particularly autonomous navigation, robotic vision, simultaneous localisation and mapping (SLAM) and robot learning. Dr. Wang's research through the ORCA Hub includes autonomous underwater drones equipped with smart stereo cameras, inertial sensors and sonar to detect the environment around them. The sensors use AI algorithms to understand the environment and plan a path for an inspection.

The team will be based in the Robotics and Autonomous Systems Lab, home to a variety of robot platforms for field robotics and autonomous systems. For marine robotics, these include autonomous underwater vehicles, unmanned surface vehicles, remotely operated vehicles, underwater manipulators, underwater communication and sensors. For ground robotics, the department is researching a wheeled mobile robot (Clearpath Husky), a van fitted with sensors (LiDAR, camera, radar and GPS) for self-driving applications and the Boston Dynamics 'Spot' four-legged robot. Aerial robots include mini drones, Kilobot large swarm robots, DJI drones and SUI Endurance Drones.

Dr Adam Stokes
University of Edinburgh liaison lead

In recognition of the partnership that underpins the National Robotarium, the academic teams within Heriot-Watt University and the University of Edinburgh collaborate closely, facilitated by two liaison leads who support strong communication between the two institutions.

Dr Stokes is Director of the Soft Systems Group, an interdisciplinary research laboratory. Soft systems represent a new way of thinking about robotics, moving away from the traditional fabrication methods and focusing instead on systems that are inherently compliant, exhibit nonlinear dynamics, and that can be manufactured at low-cost. His group also studies swarm robotics with a focus on sensing. Inspired by nature, this class of systems can be valuable in tackling real world problems like the search for survivors following an earthquake. Dr Stokes' experience also includes the revolutionary Connect-R project through which robots build themselves into scaffolding to help decommissioning activity in hazardous environments like nuclear facilities. He is a participant and Co-I in the ORCA Hub, delivering the Limpet sensor, a cost-effective, integrated multi-sensing device.

Professor Subramanian Ramamoorthy
University of Edinburgh liaison lead

Professor Ramamoorthy is Personal Chair of Robot Learning and Autonomy in the School of Informatics at the University of Edinburgh, where he has been on the faculty since 2007. An executive committee member for the Edinburgh Centre for Robotics, his research is focussed on learning, adaptation and control mechanisms to enable autonomous robots to cope with the uncertain and the unknown. In turn, this has led him to explore scientific questions about (bio)physics-informed machine learning, multi-scale modelling and active sensing systems. Among other applications of this work, Professor Ramamoorthy uses his research in healthcare technologies, biomedical devices and biophysical discovery platforms. He is also part of the team of academics leading the way in developments in offshore robotics for the ORCA Hub.

Professor Ramamoorthy was recently appointed to lead the £3.2 million governance and regulation of Trustworthy Autonomous Systems (TAS) Node. The team is tasked with developing a novel framework for the certification, assurance and legality of TAS, addressing whether such systems can be used safely.

OUR FACILITIES

The design of the new building and its unrivalled facilities will encourage the collaborative approach that is at the heart of the National Robotarium's ethos. Facilities include a partner suite: an area dedicated to fostering collaboration between industry partners, academics and government.

The innovative design means that the cutting-edge resources of the National Robotarium will be matched by the building itself, with a focus on sustainability and energy efficiency. An exterior projector and state-of-the-art linear grazing luminaire technology allow for the projection of colour and graphics onto the façade. In winter, the intelligent façade will provide solar heat and recycle warm air. An ecological zone will integrate sustainable urban drainage systems, while a solar PV array will be installed on the roof. EV charging spaces will also be available.

The 40,000 sq ft building will provide distinct and bespoke Research and Development space and unique laboratories for each of the three major areas of research. Robotics & Autonomous Systems (RAS) will house an Autonomous Systems Laboratory, researchers within Human & Robotics Interaction (HRI) will have access to an Assisted Living Lab, making it possible to trial social care technologies in a realistic home setting, and High Precision Manufacturing will benefit from dedicated ULTRA laser labs and a biosafety facility.

The Autonomous Systems Lab

The autonomous systems laboratory will be home to a variety of robot platforms for field robotics and autonomous systems, including marine, ground and aerial robots as well as manipulation systems. In addition, there will be test facilities for robot deployment and data collection in realistic scenarios, which will enable the testing and development of innovative technology. These facilities will include substantial indoor space with a VICON motion tracking system for ground and aerial robots, The lab will be connected to GPU servers with more than 30 Nvidia GPUs for cloud computing and AI.

The Assisted Living Lab

The Assisted Living Lab will build on the world's first open and remote-access multi-disciplinary living lab which is already researching and creating solutions for Ambient Assisted Living (OpenAAL). The new lab will offer real-time interaction with its sensing, automation and robotic equipment over the internet, meaning that time and distance are not barriers to collaborative research.

The lab will target the fast co-creation of scalable and affordable solutions to support the care of vulnerable people. Using telepresence technology, Internet of Things (IoT) and cloud technologies, the lab will be a collaborative platform where researchers, industry and care providers, alongside end users of assisted living services, can co-create technologies enabling non-intrusive monitoring of behaviour and vital signs, patterns and trends in behaviour and individual health statuses.

The Laser Labs

The National Robotarium building will be home to nine laser manufacturing laboratories. Seven of these will house individual laser systems with the associated workstations using a variety of laser types to develop a range of laser manufacturing processes. Another will be a multi-workstation lab, splitting a single flexible laser and looking largely at internal material modification, also known as waveguide inscription. The final optical lab will have three optical benches to provide a flexible workspace for development of high precision manufacturing processes.

There will be two diagnostics labs with ultrasonic baths, microscopes, sectioning equipment and surface profilers to allow for characterisation of processed materials. Additionally, there will be a Category 2 bio lab for preparation and characterisation of biological samples – potentially including human tissue – as part of our developing surgical and medical laser research.

OUR ACTIVITIES

Within the Edinburgh and South East Scotland City Region Deal activities are aligned with the acronym TRADE: Talent (the development of work place skills), Research (fundamental research activities), Adoption (the take up of research by business and industry), Data (the creation of new data sets with societal and commercial value), Enterprise (support for spin-outs and start-ups and the commercialisation of intellectual property). We have therefore aligned the description of our activities below with each of these topics. Some activities such as Research are well developed whereas others such as Data are works in progress.

TALENT

Heriot-Watt University and the University of Edinburgh offer a joint 4-year PhD training programme, drawing on our extensive experience with postgraduate teaching and research supervision in the area of robotics and autonomous systems.

This provides an individually tailored course and project portfolios taken during the first year of the programme that ensures all students have an excellent general grounding in current theory, methods and applications, with flexibility for strategic individualised study, and strong support leading to a specialised PhD project.

There are currently 87 research projects underway at PhD level and some examples of these projects are provided in the case studies below.

As we work to build the next generation of roboticists and artificial intelligence specialists and researchers, we aim to attract the brightest minds and entrepreneurial brains by running bridging masters courses, directed at students whose undergraduate degrees are in an unrelated field such as maths or psychology. Study options include master degrees in **Human-Robot Interaction**, **Artificial Intelligence** and **Data Science**.

MEET THE NEXT GENERATION OF ROBOTICISTS

Emilyann Nault,
PhD Student, Robotic Rehabilitation

What does your research entail?

My research involves the development of a socially assistive robotic system to maximise engagement with cognitive rehabilitation for individuals with mild-cognitive impairment (MCI) and dementia. To achieve this goal the system will adapt robot behaviour, rehabilitation tasks and sensory feedback based on the level of engagement assessed from physiological sensors.

How do you expect your research will impact society?

As the population of older adults increases, so does the need for therapeutic intervention. Through engaging robotic rehabilitation sessions earlier, we aim to slow the rate of decline, in turn alleviating the growing pressure on the healthcare system.

What's the biggest challenge you face in your research?

The most prevalent challenge is the complexity and diversity of symptoms. The rehabilitation of someone with memory problems is very different to that of someone who has trouble with executive functioning. Using a robot brings the added benefit of being able to repeat instructions in different ways, as many times as needed, without getting 'tired' or 'frustrated'.

How did you become interested in robotics?

As someone who was always interested in a healthcare-based career, the current and potential impact of technology on this field fascinated me. During an internship with my current PhD supervisor, Professor Lynne Baillie, I developed a system where the Pepper robot facilitated upper limb rehabilitation for stroke survivors. This experience showed me the potential for using socially assistive robots in healthcare.

What do you hope to achieve through your robotics research?

I aim to create a robotic system to engage older adults in cognitive rehabilitation. The most unique aspect of this is the integration of sensory feedback and physiological sensors. Additionally, adaptability is a vital attribute in creating an engaging system. Utilising physiological sensor readings will allow us to adapt the system in real-time to maximise engagement. I hope to help identify more effective practices for delivering robotic cognitive rehabilitation.

Theodoros Georgiou,
Research Associate,
Department of Computer Science

What does your research entail?

My work explores interactions between humans and robots for healthcare applications in the home environment. These interactions are informed by potential end-users.

How do you expect your research will impact society?

People are living for longer. With this comes the expectation of remaining active and independent for longer than in previous decades. However, physical and neurological conditions and injuries may prevent people from being as active as they want, and rehabilitation has been shown to be of paramount importance to quality of life. Resources are limited and socially assistive robots can alleviate the burden on the health professionals while maintaining high quality support.

Additionally, our work at the HRI (human-robot interaction) lab investigates the acceptance of robots in the home environment, such as the work we did with MiRo, which monitored people who experience frequent falls.

What's the biggest challenge you face in your research?

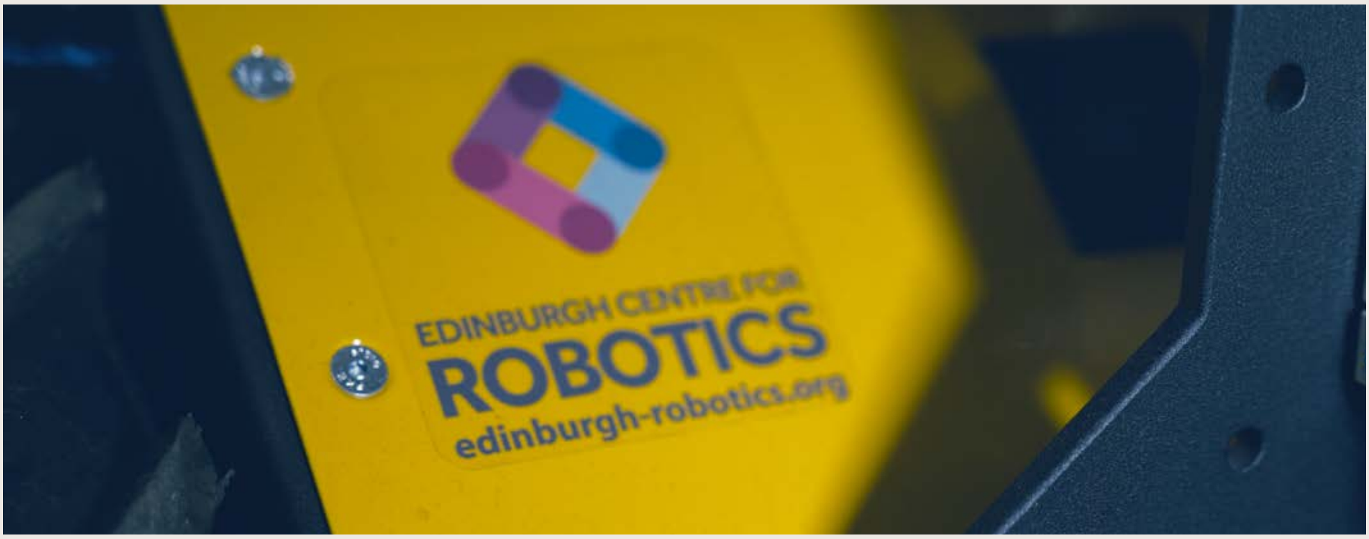
Addressing misconceptions around robot capabilities and communicating robots' limits outside the controlled environment of a lab. There is an image of robots being capable machines that can replace humans and work independently towards common goals. Even though this is not entirely fiction, and robots can (and often do) augment human abilities and capabilities in both the home and the work environment, we are still not entirely ready to talk about total autonomy for socially assistive tasks.

How did you become interested in robotics?

Interestingly enough it was films and the way robots are portrayed on the big screen!

What do you hope to achieve through your robotics research?

Ultimately, robots are machines designed to perform specific tasks and/or assist humans. My research explores the social connections between user and machine and how they can be used in the home environment. This may be for social companionship, physical rehabilitation coaching or personal safety, thereby facilitating round-the-clock care that could have a profound impact on the already over-stretched healthcare sector.



CASE STUDIES: PHD STUDENT RESEARCH PROJECTS

Research Area: Robotic Navigation

Project: Online Mapping and Motion Planning under Uncertainty for Autonomous Safe Navigation in Unknown Environments

PhD candidate: Èric Pairet

Supervisor: Professor Yvan Petillot.

Objectives

Autonomous robots are increasingly employed to assist humans in hazardous or inaccessible environments. Examples include rescue missions in disaster response scenarios, in-water ship hull and wind turbine inspections, underwater archaeology, and deep underwater and space exploration. A fundamental requirement for a robot engaged in any of these applications is to be adept at navigating autonomously through highly unstructured and hostile environments. The robot has to base its decision making on on-board sensors with limited accuracy and risk poor localisation and uncertain manoeuvrability. Therefore, it is essential to consider these constraints when planning deployments. Our goal was to endow a robot with online mapping and motion planning capabilities to safely navigate unexplored environments.

Approach

Our strategy is an iterative mapping-planning scheme capable of continuously modifying the vehicle's motion plan towards a desired goal according to the incremental environmental awareness. The vehicle's surroundings are encoded as an uncertainty-aware map. Then, over this representation, the framework plans feasible trajectories. Online computation constraints are met with novel advancements on multi-layered planning and an efficient evaluation of uncertainties. The framework provides at any time motion plans that are guaranteed to be feasible and safe.

Results

Extensive benchmark results demonstrate that our approach significantly outperformed by multiple orders of magnitude previous methodologies in terms of probabilistic accuracy and computation time. Deployment on an unmanned aerial vehicle (UAV) and on an autonomous underwater vehicle (AUV) demonstrated suitability of the proposed method to address the challenge of probabilistically-safe autonomous navigation in unknown environments while being suitable for systems with limited on-board computational power.

Impact

Previous methods in the literature uniquely focus on particular challenges of robot navigation, thus not providing a full strategy. Our work is the first generic end-to-end architecture capable of jointly dealing online with kinodynamic and probabilistic constraints in unknown environments for safe robotic navigation. Any mobile robot, either terrestrial, maritime or aerial system, can benefit from this work.

Future Work

The modularity of the proposed framework allows for multiple extensions and variations. A possible extension is leveraging the multi-resolution encoding of the uncertainty-aware maps to check the compliance of the safety guarantee at different resolutions. Formulating this process as a multi-resolution kernel checking could speed up computations even further. Also, the conducted experimentation pointed out that automatically adjusting the replanning period might be beneficial, as well as studying more intelligent synergies within the multi-layered planning scheme.

Research Area: Computer Vision based damage assessment

Project: Masonry crack detection with Faster R-CNN

PhD candidate: Borja Marin

Supervisor: Dr Mustafa Suphi Erden

Objectives

Uncertainty when measuring variables such as time, environmental conditions, change in load patterns and frequency, or quality of the materials used, requires regular inspections to ensure the good working condition of a structure. According to Network Rail, it has a £7 million rolling program in Scotland for railway bridge improvements. This gives an idea of the cost and the importance of cost-effective inspections. This study researches a drone inspection system that allows inspectors to make predictions without manually inspecting a structure. We developed machine learning with convolutional neural networks for crack detection.

Approach

We used deep learning in masonry structure defect identification using RGB images. This allowed us to embed a small system on a drone for fast operation. We adopted Faster R-CNN architecture to perform defect detection. Generating a set of reference bounding-boxes to train the deep learning algorithm was challenging. To overcome partial detection of cracks, we proposed a detection scheme that recovers the full size of a defect by splitting the original image into sub-images. We generated an annotated crack dataset with 3000 images with different surface textures and lighting conditions. By comparing the performance of three networks (in terms of run-time, precision, classification accuracy and network complexity) we investigated the most suitable architecture to embed on a drone.

Results

Our progressive detection framework successfully recovered cracks with four sub-images for any network, generating more optimised bounding-boxes that contain the defect almost completely. The performance increased 15% for the Mobilenetv2 network, making it the perfect fit for a drone deep learning based crack detection platform.

Impact

We aim to provide a defect detection system that can be embedded onto a drone, significantly reducing the costs of structure inspections and risks for employees, while providing real time structural health data. This improves how visual inspections are carried out, helping experts better plan and determine areas that need immediate action.

Future Work

Part of a research programme to inspect the brickwork and masonry assets of railway bridges, our work will support the development of a UAV capable of inspecting arched structures with the implementation of a wall-following, path-planning algorithm, using ultrasonic sensors and a deep learning detection framework.

CASE STUDIES: PHD STUDENT RESEARCH PROJECTS

Research Area: Simultaneous Localisation and Mapping (SLAM)

Project: Radar based Large-Scale SLAM in All Weathers

PhD candidate: Ziyang Hong

Supervisor: Dr Sen Wang

Objectives

To achieve 24/7 autonomous navigation in large-scale, outdoor environments, a robust SLAM system must be able to operate in extreme weather conditions. Recently, the emerging Frequency Modulated Continuous Wave (FMCW) radar sensors which work in various weathers have been increasingly adopted for self-driving cars and autonomous robots. This project aimed to investigate whether these radars can be used for robust SLAM in large-scale environments in extreme weather conditions, such as heavy snowfall.

Approach

Given a sequence of radar scans, our system *RadarSLAM* aimed to estimate radar (robot) poses and a global consistent map using graph SLAM. To this end, the system is designed to have four main subsystems: pose tracking, local mapping, loop closure detection and pose graph optimisation.

Results

We tested our system on a publicly available radar localisation benchmark and on self-collected data. The self-collected data included multiple adverse weather sequences with fog and snow. We showed that, among all the three sensor modalities, only the radar system is able to operate and localise reliably in all weather conditions.

Impact

This work has shown the superiority and reliability of our proposed *RadarSLAM* system with FMCW radar to enhance the capability of automotive vehicles navigating in large scale and extreme environments.

Future Work

We will investigate the fusion of Inertial Measurement Unit with radar for better accuracy. We will also be looking into the reusability of the map produced by our SLAM system and perform long-term localisation tasks on it.

Research Area: Robotic Grasp Affordances

Project: Self-Assessment of Grasp Affordance Transfer

PhD candidate: Paola Ardón, Èric Pairet

Supervisor: Dr Katrin Lohan,
Professor Subramanian Ramamoorthy,
Professor Yvan Petillot, Dr Ron Petrick

Objectives

Our goal is to endow an artificial agent to self-assess the performance of an affordance task. Reasoning about object grasp affordances allows an autonomous agent to estimate the most suitable grasp to execute a task. While current approaches for estimating grasp affordances are effective, their prediction is driven by hypotheses on visual features rather than an indicator of a proposal's suitability for an affordance task, and therefore cannot guarantee any level of performance or successful task completion. Our work developed a pipeline for self-assessment of grasp affordance transfer (SAGAT) based on prior experiences.

Approach

Our approach extracted multiple grasp configuration candidates from a given grasp affordance region. The outcome of executing a task by the candidates was estimated via forward simulation. These estimates were employed to evaluate and rank task performance and grasp configuration candidates via a heuristic confidence function. The ranking was stored in a library of task affordances. We evaluated the method's efficacy on addressing novel task affordance problems by training on one single object and testing on multiple new ones.

Results

We used seven synthetic and real objects with notably different features to test pour, shake and handover. We used the policies in the learnt library of task affordances to replicate the pour, shake and handover tasks on each object, for each grasp affordance, and for each method when used as stand-alone and combined with SAGAT. We ran a total of 126 tasks on the robotic platform. Our approach enhanced the deployability success for all the tasks by 11.7% compared to state-of-the-art methods.

Impact

Our approach can be used on state-of-the-art methods for grasp affordance detection to enhance the deployment reliability of a task.

Future Work

Future work includes implementing a task planning layer that connects actions with grasp affordances to perform and self-assess multiple tasks.

CASE STUDIES: PHD STUDENT RESEARCH PROJECTS

Research Area: Perception, Autonomous Vehicles

Project: DeepBEV: A Conditional Adversarial Network for Bird's Eye View Generation

PhD candidate: Helmi Fraser

Supervisor: Dr Sen Wang

Objectives

Obtaining a meaningful, interpretable yet compact representation of the immediate surroundings of an autonomous vehicle. Many solutions to this problem involve multiple cameras or other range finding sensors, increasing cost and complexity. We proposed a top-down, ego-centric 'bird's eye' view generated from a single image taken by a monocular camera. Crucially, we formulated this as an adversarial learning task: tasking a generator model to produce a bird's eye view plausible enough to be mistaken as a ground truth sample.

Approach

We achieved our objective by a conditional Wasserstein Generative Adversarial Network with gradient penalty trained on publicly available datasets. Our model is composed of two sub-networks: a generator network and a critic network. The generator network is tasked with producing bird's eye view representations from an image, while the critic network is designed to assign a 'realness' score to this representation. In effect, the generator attempts to fool the critic into thinking that its output is a more truthful representation than the ground truth.

Results

Evaluation was performed on several publicly available datasets such as the nuScenes dataset and Virtual KITTI 2, measuring the similarity of predictions versus the ground truth.

Impact

We showed that a model trained in this way generalises better between datasets, as well as being lightweight and real-time capable. Our approach is inexpensive, only requiring data from a single monocular camera during inference, and not requiring more complex sensors such as LiDAR or radar.

Future Work

Future work will involve improving accuracy and robustness, making it suitable for deployment on an autonomous vehicle, as well as investigating its applicability as an error estimator for bird's eye view representations

Research Area: Biorobotics

Project: Using a quadcopter to model the visual navigation behaviours of flying insects

PhD candidate: Jan Stankiewicz

Supervisor: Professor Barbara Webb, Professor Yvan Petillot

Background

Biologists have demonstrated that some wasps are able to locate their ground nest sites using primarily visual information. This is particularly impressive given that wasp eyes have 1/60th the acuity of our own. We have previously demonstrated that a path integration circuit enables wasps to navigate within 15m of their nest following a foraging excursion of up to 1km. Here we aimed to demonstrate how to bridge the gap between the path integration circuit and visual contact with their nests.

Approach

We were inspired by the 'visual route following' approach of the desert ant. The literature shows that if an agent periodically stores view 'snapshots' along a route, it can subsequently use this information to follow the same path in future. While porting this approach to a 3D task-space leads to a problem of greater dimensionality, we found that an aerial perspective provides salient information for the task of localisation in the XY plane. We developed a quadcopter so that we could test our behavioural model in the real world. We collected a dataset comprising a straight outbound path of downward facing images and a corresponding inbound route. Each image was geo-tagged with a differential GPS sensor reading. This enabled us to trial candidate view matching pipelines offline and optimise. We compared six different approaches and found that a complex wavelet transform provided a comparison space that detected view overlaps with 100% accuracy and had the widest catchment area of any arrangement. Given the specification of a reliable view matching pipeline, a route following procedure could be specified and its performance evaluated in different environmental conditions.

Results

Our biorobot can robustly navigate along previously traversed routes. We found this procedure to be 100% effective across a variety of different real and simulated environments. Simulated worlds that make use of texture tiling are problematic, indicating that our procedure is particularly suited to the chaotic nature of natural environments. We showed that this approach is amenable to very low visual acuities (6°/pixel) and that the camera angle can be pitched up to 60° without any loss in performance. We also showed that the approach can be used to follow curved paths.

Impact

We have created a line-following procedure, where the track can be procedurally generated on-the-fly. We have also developed a new hypothesis that outlines how ground nesting wasps may locate their nests. A significant barrier to the wider deployment of autonomous micro aerial vehicles is the lack of lightweight navigation systems that can operate in GPS-denied environments. Our approach has a low computational overhead compared to state-of-the-art SLAM systems and can be applied directly to situations requiring point-to-point navigation.

Future Work

We aim to use computer vision to record 3D trajectories of wasps returning to nests, thereby testing our route-following hypothesis in addition to quantifying the precision with which these animals navigate. We also aim to interrogate the failure modes of the approach by testing across longer routes and investigating the impact of different lighting conditions.

For details of more PhD research projects see the Annual Review 2019-20 of the **Edinburgh Centre for Robotics**.

RESEARCH

As mentioned above we have made a positive start in securing new research projects by building on the expertise of the ECR. This funding is predominately from UK Government and EU sources and our immediate aim is to diversify the sources of our funding by growing our level of direct support from industry through the implementation of a membership model and direct project funding. Below we have provided examples of some of our current projects and areas of expertise.

The ORCA Hub

One of the strategic projects within the National Robotarium, the Offshore Robotics for the Certification of Assets (ORCA) Hub is a research initiative developing Robotics, Artificial Intelligence and Autonomous Systems for the Offshore Sector. ORCA Hub supports a long-term industry vision for autonomous offshore fields that will be operated, inspected and maintained from shore. Significant industry engagement has been achieved, with 68 individual research projects spinning out from ORCA activities. ORCA projects have also benefitted from PhD sponsorships, user engagements, and the supply of equipment, hardware, software, data and asset samples. There are a further 16 projects in discussion or pending approval, with an estimated value of over £6 million. One spinout company has been created and two more are in the pipeline. Two patent applications enabling developments to be licensed to companies are in progress.

In June 2021, the ORCA Hub announced it had been awarded £2.5m of further funding from UK Research and Innovation (UKRI) to expand robotics research into new sectors. The new funding will be used to deliver demonstration projects with industrial partners, including the inspection of wind turbine foundations and the deployment of Industrial Internet of Things (IIoT) sensors, and an extension of ORCA Hub's activities to benefit other sectors, including construction, decommissioning and waste management.

Spot

The National Robotarium is working with a Spot robot, created by US-based Boston Dynamics, in its exploration of how robots can support humans in hazardous environments like offshore energy inspection and disaster recovery. The £60,000 robot is fitted with telexistence technology, which lets humans experience an environment without being there, using devices such as microphones and cameras.

The first application of the technology will be in the construction industry. By fitting the robot with Lidar, the robot will create a picture of its surroundings in real-time, including the positioning of structural elements and the nature and location of defects, meaning that data can be relayed to multiple experts at once, anywhere in the world, and construction companies, regardless of their location, can benefit from worldwide expertise. Using Spot in this way has the potential to speed up the construction process, reduce costs of re-work, detect hazards, increase efficiency and improve quality control.

Credit Chris Watt Photography and ORCA Hub

Open Ambient Assisted Living (OpenAAL) Lab

The OpenAAL lab uses digital twin, Internet of Things (IoT) and cloud technologies to provide a platform where researchers, industry and care providers alongside end-users of assisted living services can co-create technology, where time and distance is no longer a barrier – any time, anyplace access. The project initially supported key priority groups in the UK whose conditions have been compounded by the social isolation measures that have been necessary during the pandemic. These include those with multi-morbidity conditions, disabilities, and those in acute stages of mental ill health.

Using technologies to enable non-intrusive monitoring of behaviour and vital signs, it is possible to detect patterns and trends in behaviour and individual health status, identify problems, support self-management, decision-making and risk assessment, triage issues, facilitate communication and social connectedness, and provide social, cognitive and physical assistance when needed. The OpenAAL is co-creating fast and scalable solutions for assisted living needs, ranging from IoT and wireless technologies to trialling WIFI to support continuous health monitoring in the home for early indications of deterioration in conditions like dementia. The project is funded by the Engineering and Physical Sciences Research Council (EPSRC) and has gained support from NHS Lothian, The Digital Health and Care Institute (DHI), Blackwood Home and Care Group, Consequential Robotics, Alcuris Ltd, Cyberselves and The Data Lab.

It is expected that telexistence technologies will increase inclusivity of access to the OpenAAL by making it possible for those unable to attend the lab in person to telepresence into a Pepper robot from home. Recent collaborative successes from a hackathon event included connecting the lab to an in-ear switch for those living with MND, a Hermes Holistic Messenger which is designed to augment virtual communication tools used in befriending applications and a post-discharge robotic nursing service model for patients who are recovering in their homes after their treatment.

Socially Pertinent Robots in Gerontological Healthcare (SPRING)

SPRING is an international collaboration that brings together eight research institutions from Europe and Asia. Funded by the EU's Horizon2020, the project is developing Socially Assistive Robots (SARs) with the capacity to perform multi-person interactions and social conversation for the first time. The project will develop new research into conversational AI, computer vision, machine learning and human-robot interaction, alongside human behaviour analysis and sensorimotor robot control, to develop a new multi-user conversational robot to enhance elderly healthcare. The work builds on the success of Heriot-Watt's Amazon Alexa Prize winning conversational AI system called Alana.

Social robot technology can have a positive impact on elderly health, such as decreasing stress and loneliness, and improving mood and sociability. Utilising social robots within healthcare settings can be highly beneficial, improving both the psychological wellbeing of elderly patients and the relationship between them and hospital professionals. One essential task they can undertake is helping to explain complex concepts to patients with limited medical knowledge.

SPRING will develop a robot that can manage group situations, with the ability to detect that there are several people in a room and engage in appropriate conversations based on its understanding that people have different roles, such as parent, carer or medical professional. It will be able to identify patients who have been waiting for an extended period or those who could be anxious, assessing who might need its assistance and engaging effectively in face-to-face conversation with patients, family members and staff as appropriate.

The technology is touch-free and hands-free, so a robot like this would be particularly useful in lowering people's fears of cross-infection, particularly in light of the pandemic. SPRING's partners include Università degli Studi di Trento, Czech Technical University Prague, Bar-Ilan University Tel Aviv, ERM Automatismes Industriels Carpentras, PAL Robotics Barcelona, and Hôpital Broca Paris.

Drone inspection of railway arches

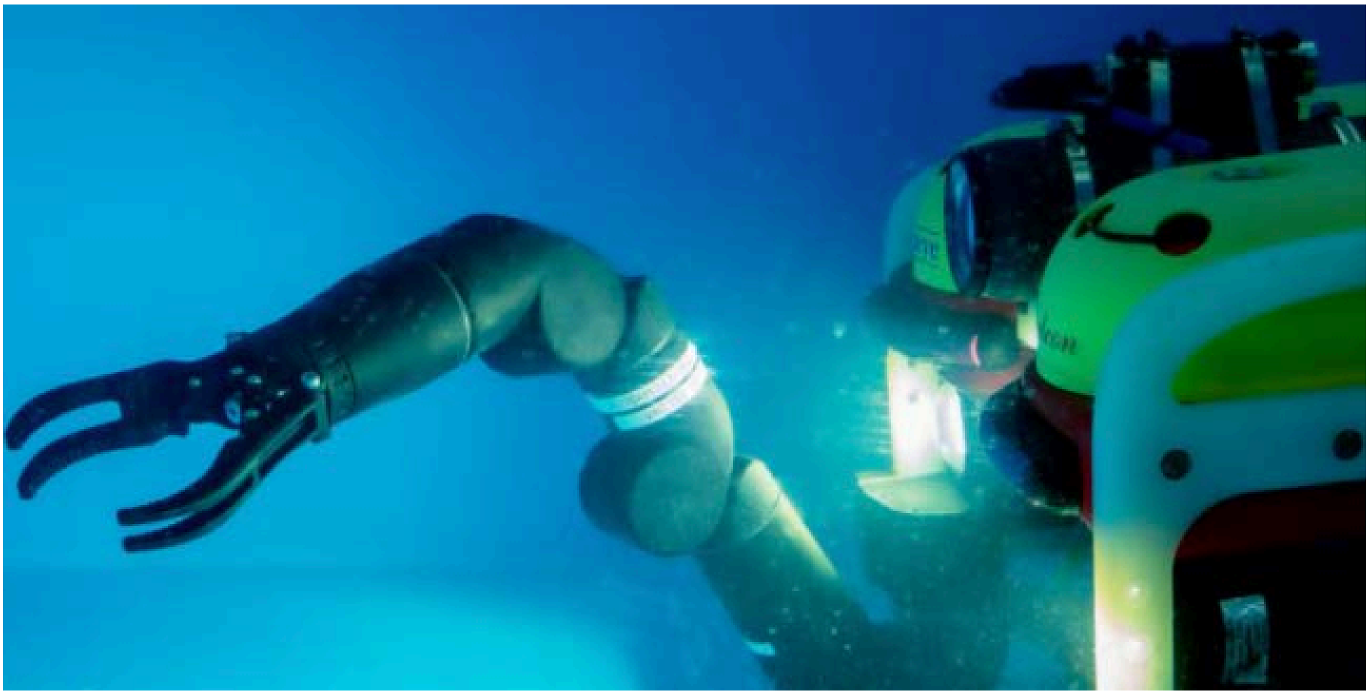
Funded by **RSSB** we are developing drone technology to inspect railway bridge archways, particularly the inner curve where access is limited. Drones will collect images autonomously under the arches and then automatically analyse these to detect defects in the structure. Defects such as cracks, spalling (flakes), water seepage, insufficient mortar, misalignment, and crushing will be examined and identified for remedial work.

Research is currently focusing on developing the drone technology that can navigate itself using proximity sensors and webcams. These will allow the drone to control itself from one edge of the arch to the other through a horizontal line and turn back to follow a parallel path on another horizontal line. This level of accuracy, including maintaining an accurate distance from the surface of the arch, means every inch of the arch will be inspected in detail. A machine learning algorithm to inspect the collected images and to detect a pre-identified set of hazards in the brickwork of the bridges will also be created.

Trustworthy Autonomous Systems programme: Governance and regulation of decision-making machines

In parallel with the work on trust being led by Professor Helen Hastie, Professor Subramanian Ramamoorthy from the University of Edinburgh is leading cross-disciplinary, fundamental research to ensure that autonomous systems are safe, reliable, resilient, ethical and trusted. The TAS programme comprises seven distinct research strands, termed Nodes. Professor Ramamoorthy's team is exploring governance & regulation, developing a novel framework for the certification, assurance and legality of TAS, and addressing whether such systems can be used safely.

Devising regulatory frameworks that can address these issues will require an entirely new interdisciplinary perspective, weaving together the technical considerations with the legal, social and ethical. The TAS Governance and Regulation research node aims to create new and improved methods for governing autonomous systems that reflect emerging use cases such as finance and medical diagnostics, conversational agents like Alexa as well as physical systems ranging from home robots to self-driving cars and planes. Trustworthy Autonomous Systems is a broad term, covering the full range of the application of AI in real systems in our lives.



3D lasers

A project on laser manufacturing applications is exploring beams that can change shape. The innovation is set to disrupt the manufacturing and healthcare technology industries, making it easier and cheaper to produce products that require highly-precise manufacturing, such as medical equipment and mobile devices.

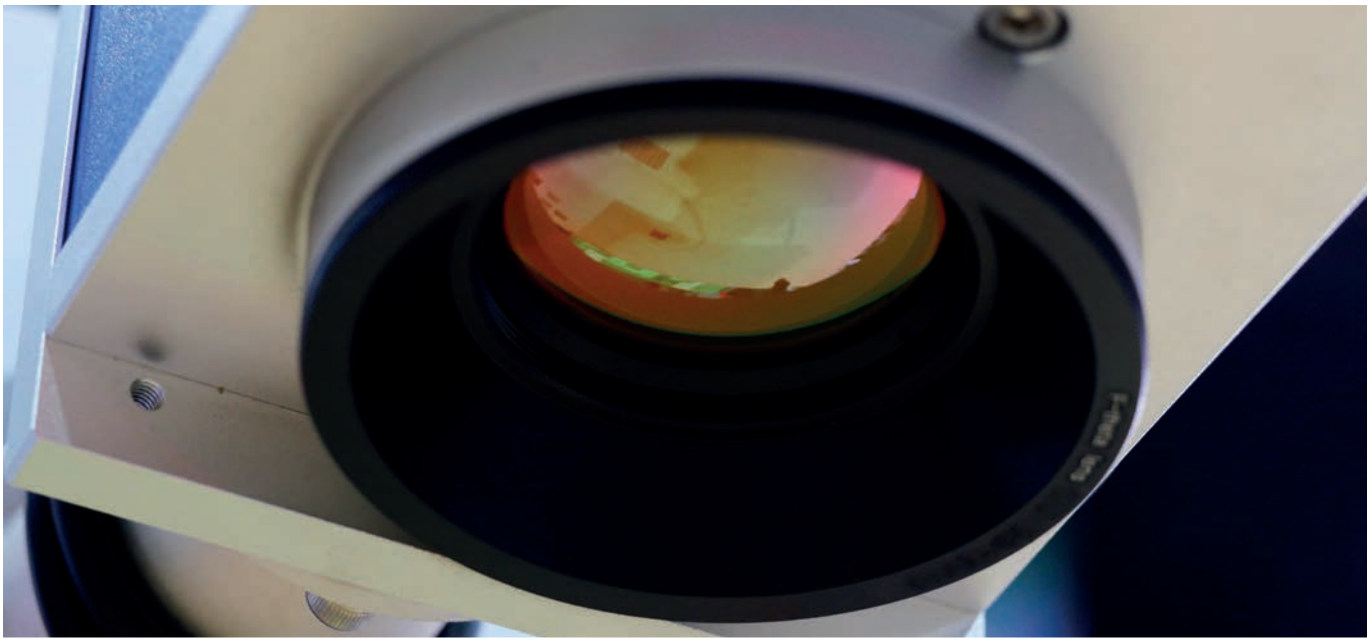
The funding from EPSRC will support the research and development of the lasers for industry application, accelerating the commercialisation of the technology for the benefit of businesses and the wider economy.

Lasers are a crucial component of modern manufacturing, with the global laser processing market projected to grow from $4 billion (£2.8 billion) in 2020 to $5.8 billion (£4.1 billion) by 2025. They are used almost exclusively by industry to produce precise incisions and mould materials into specific shapes. However, this approach to laser-based manufacturing depends on melting or vaporising the material, which means the laser's energy must be focussed on the right points. The standard laser beam shape makes it difficult to tailor this for specific manufacturing processes, decreasing efficiency and limiting what can be made.

The research to be undertaken at the National Robotarium will develop laser beams which have been specifically designed to meet the exact manufacturing requirements of products, improving efficiency and precision. The new technique could be harnessed to improve how holes for sensors and cameras on smartphone screens are drilled and to increase the density of information on semiconductor chips, helping to keep up with the ever-increasing demand for more memory in devices.

Medical applications could include cancer surgery, where it is hoped more precise medical instruments could reduce ablation, allowing for the resection of tumours without removing healthy surrounding tissue. In an academic partnership, the project's research into this kind of medical application will be supported by Professor David Jayne at the University of Leeds. Other examples include telecommunications, microscopy, and glass processing to make optical devices. Glass processing is important in the production of waveguides, which are used to transmit high frequency electromagnetic waves, including radar, microwaves and radio waves.

In keeping with the National Robotarium's focus on industry collaboration to solve global challenges, researchers will be working with three industrial partners throughout the project to optimise the approach and final product for commercial application. Industrial partners PowerPhotonic, Oxford Lasers and Gooch & Housego will also support testing in real-life industrial settings.



ADOPTION

In terms of the City Region Deal "Adoption" is used to describe activities that enable the use of research in the development of new products and services. Below we have provided examples of current projects where we are working directly with industry to facilitate this outcome.

Autonomous drones: Asset repair made safer

The ORCA Hub is researching the use of autonomous Unmanned Aerial Vehicles (UAVs) for monitoring, inspecting and repairing offshore infrastructure. The aim of the work is to provide a safe and cost-effective method of carrying out these tasks in hard-to-reach, hazardous and dangerous environments.

The research is looking at using UAVs for detecting and repairing damaged offshore infrastructure by using stereo-vision sensing technologies, optic-flow based stabilisation techniques, impact protection mechanisms and precise deposit of repair material using tensile perching.

The benefits of the technology include removing people from dangerous inspection and repair tasks, enabling resident aerial inspection and repair systems that could eliminate the need for support vessels and reduce the time taken to mobilise an inspection or repair, and carrying out work more quickly, efficiently and cost effectively.

Possible applications are pipeline and vessel leak detection and repair, wind turbine blade damage monitoring, inspection and repair, and autonomous deployment of sensors in areas of interest for continuous monitoring.

MIRIAM: Building trust in human-robot teams

MIRIAM - Multimodal Intelligent inteRactIon for Autonomous systeMs - is a conversational interface being developed to manage and monitor autonomous Unmanned Vehicles (UxVs) as they work independently, in teams or in swarms to carry out their missions.

MIRIAM enables operators, pilots and technicians of autonomous UxVs to interrogate the systems' actions, state of health and mission status in real time through natural language, allowing users to ask on-demand queries and explanations of behaviour.

Interaction can be in the form of a group chat with the MIRIAM personal assistant, through voice interaction via a radio, smartphone or home-speaker, or through a robotic assistant.

Benefits include building trust within human-robot teams for safer and more efficient hazardous operations, supporting joint human-robot decision-making for optimum efficiency, balancing operator, pilot and technician information intake ensuring full engagement in autonomous operations for safer UxV missions, and helping operator, pilot and technicians increase their understanding and performance during missions.

Possible applications of the technology are mission monitoring for Autonomous Underwater Vehicles (AUVs), autonomous Unmanned Aerial Vehicles (UAVs) and autonomous Unmanned Ground Vehicles (UGVs), and having a virtual support operator, or second pilot, for remote vehicle operations, e.g. Beyond Visual Line of Sight (BVLOS).

The Limpet sensor: building asset intelligence

The Limpet sensor is a cost-effective, integrated multi-sensing device designed for deployment in large collectives on and around offshore assets for asset integrity monitoring and inspection.

The Limpet is currently equipped with nine sensing devices and five methods of communication integrated into a single, robust and compact platform. The Limpet enables asset owners, operators and duty holders to effectively monitor a multitude of integrity related parameters for real-time and predictive asset monitoring.

The benefits of the Limpet sensor are many:

- Small, compact, moveable and retrofittable installation enables monitoring of any area of interest providing greater knowledge and confidence about the integrity of offshore assets.
- Multiple sensing inputs provide greater data capture of key integrity related measurements for better decision making.
- Multiple communication methods for long and short range, high and low bandwidth data transfers ensuring the information needed is available when required.
- Low power, long life data collection for continuous asset monitoring ensuring faults and issues are raised well in advance of critical failure.
- Integrated with Robot Operating System (ROS) to allow cross-Limpet, cross-robot mission collaboration, creating a completely wireless robot control and asset monitoring network.

Connect-R: uniting academic skills and industry specialisms to develop real world solutions

Dr Adam Stokes' experience in soft robotics includes the revolutionary **Connect-R** project, a new robotic solution to the challenges of maintenance and decommissioning in the nuclear, oil and gas industries, in which robots build themselves into scaffolding.

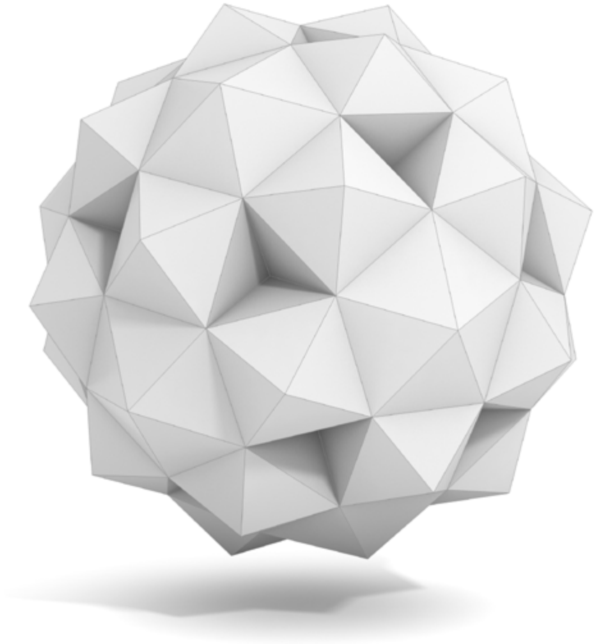
The safety risks to personnel in such areas as oil fields, mining and space can be mitigated by the use of autonomous robotic systems which can perform the required tasks in these hazardous environments.

In addition to challenging working conditions, the risks of operating in such environments include limited time windows for operation, remote bases, reduced access through which to deploy the systems, the presence of unstable structures that prevent occupation, heavy objects, dangerous chemicals, toxic materials and radiation.

The Connect-R team is a collaborative group of academics, SMEs and large enterprises including Barrnon Ltd, Jigsaw, RACE (UKAEA), Ross Robotics, Tharsus and Royal Holloway London, that is developing an industrial-scale, self-building, modular, robotic solution to provide access to work sites in these hazardous environments. This highly specialised robotic creation combines AI, advanced engineering techniques and the most cutting edge research findings available at this time.

The scope of the project ranges from the design and build of the actuator modules, to task planning and functional decomposition.

DATA



Data is a growing area of activity for the National Robotarium, as we anticipate the commercial value of future collective datasets and accessibility of big data.

We have seen the formation of a university-wide Data Task Force to develop the Heriot-Watt University data strategy. This will establish an innovation pipeline and identify data commercialisation opportunities. Additionally, we continue to work with partners at Edinburgh International Data Facility and across the other Data Driven Innovation (DDI) hubs within the Edinburgh and South East Region City Deal to develop a data strategy that can be embedded within all relevant National Robotarium activities.

ENTREPRENEURSHIP

An important activity within the National Robotarium is its ability to move innovative products and services rapidly from laboratory to market, to develop new prototypes and support early stage product development within an incubator environment that drives productivity. This will require the maintenance of strong links with industry and best use of the flexible facilities designed into the building. These will allow companies to develop technologies and carry out challenge-based innovation in a safe environment.

A catalyst for entrepreneurship and job creation, its accelerator programme will support and develop innovative start-ups, building relationships with relevant business sectors and connections to international markets.

We are working hard to develop a pipeline of disruptive robotics spinout companies that will take innovative product development to the stage of production, societal benefit and commercial viability. The first of these is Alana AI, described below. There are also two further spinouts in the pipeline and we look forward to announcing details of these soon.

Alana AI: cutting-edge technology targeting a fast-growth global market

Alana AI is a Heriot-Watt University spin-out developing artificial intelligence (AI) software that can understand and respond to human conversation. The business has experienced high demand for its technology amid an already exponential increase in sales of touch-free devices worldwide that are expected to speed up in the wake of the pandemic.

A market differentiator for Alana AI is the software's ability to manage conversations during long interactions, while learning about the user's interests. This makes it possible for the AI to proactively suggest new and relevant subject matter. Alana can converse about a wide variety of information sources, and this makes Alana the perfect assistant across sectors where users need to access large amounts of information in an efficient and user-friendly way.

The pioneering conversational technology developed by Alana AI has already been recognised as a two-time finalist (2017, 2018) in the Amazon Alexa Prize, and the company is working with clients across education, healthcare, and finance. In education, it can serve as a personal tutor; in healthcare, it can help reduce isolation for patients and support carers when human interaction is not possible; and in finance, it can help streamline front and back-office processes which are often prone to human error.

The founding team at Alana includes some of the world's leading experts in conversational AI, machine learning, human-robot interaction, and multi-modal interfaces, including the National Robotarium's Professor Verena Rieser and Professor Oliver Lemon.

OUR GROWTH TARGETS AND KPIs

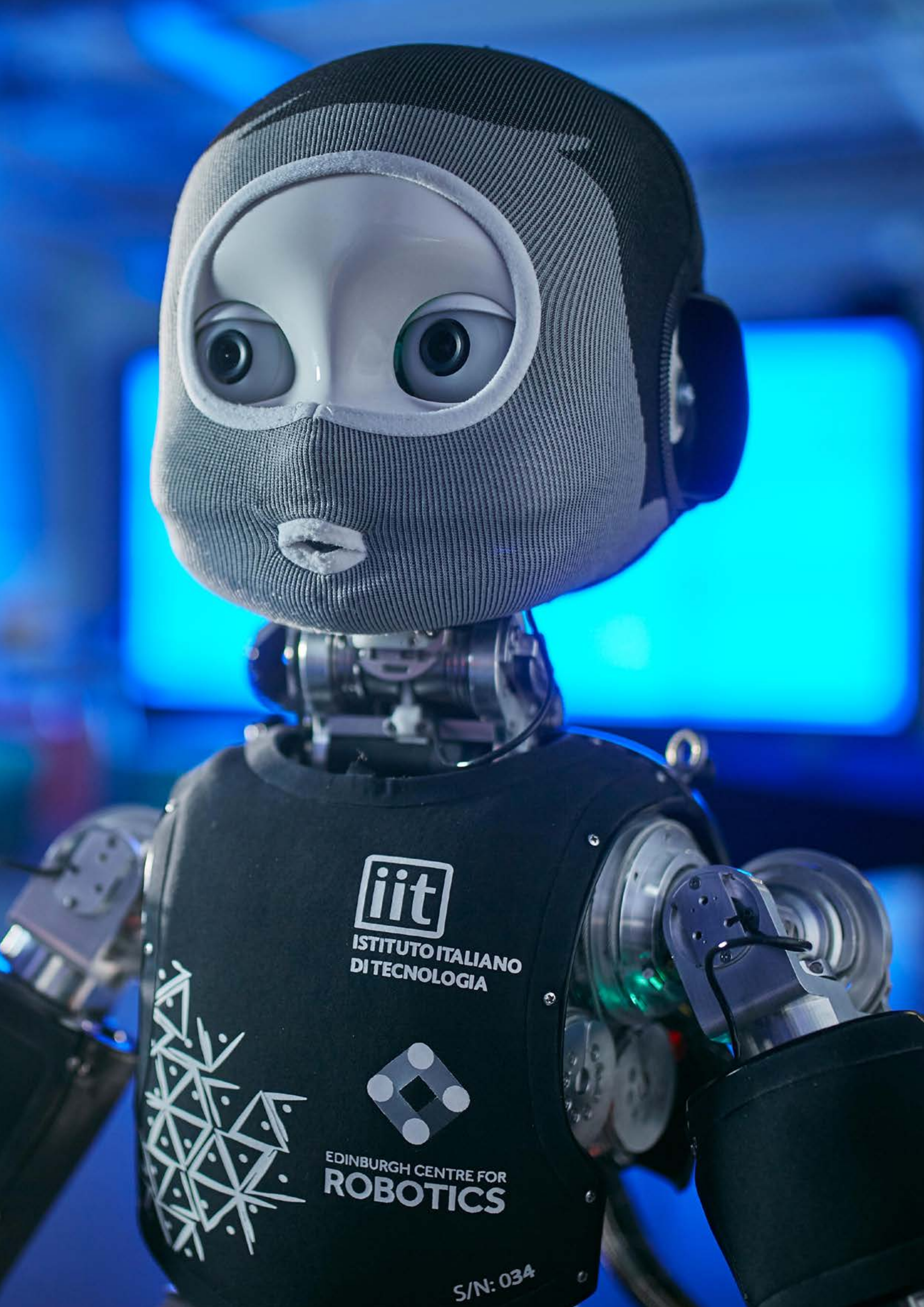
The performance of the National Robotarium is measured using a set of KPIs which underpin the funding received from the Edinburgh and South East Scotland City Region Deal. These KPIs are cumulative totals measured over the 15 years of the City Deal programme. However, in the case of the National Robotarium both universities wish to go beyond these and have therefore set out a trajectory to achieve this by the setting of interim annual targets.

Progress has been made towards many of these already and at the present time we are working to develop a robust data collection methodology that identifies growth arising from National Robotarium activities from related but separate activities taking place through associated academic units.

Table 1 provides a definition of the meaning of each of our growth targets and KPIs.

TRADE Theme	Key Performance Indicator	Summary
Talent	Industry sponsored PHD	Maintaining a leading training offer in the City Region through ability to access the latest research and facilities in a rapidly changing field an increasing the ability to apply data to “real world” problems
	Public Engagement	Extending the reach of RAS into local schools to enable better public access to the activity being undertaken to build awareness of and trust in the RAS economy.
Research	UK Research Councils Funding	Extending the scope and scale of RAS research undertaken in the City Region, improving the range, quality and critical mass of facilities available to leverage more research investment, in particular larger scale private investment.
	Industry & Commerce Funding	
	Other Funding Sources	
	Co-funded Projects	Creating the conditions for interaction and coproduction.
	Publications	Generate over new publications illustrating the direct impact of our research in Scotland.
Adoption	Strategic Sponsorship (£200k per annum)	Extending the number and level of partnerships with public and private sector partners through co-funded applied research and coproduction activities, using a tiered model with related benefits.
	Core Sponsorship (£40k per annum)	
	Affiliate Sponsorship (No cost)	
	Facility Hire	Providing access to “Living Lab” capability which is in high demand from industry to help test and develop products in real world, safe, conditions which can be hard to produce in isolation.
	CPD	Improving access to in-work training through an improved Continuing Professional Development (CPD) offering.
Data	Commercialisation	Agreeing more data partnerships with partners and improving the accessibility, usability and cost of access to data assets for wider user groups to underpin more research, adoption and entrepreneurship activity.
Entrepreneurship	Spin-Out/Start-up	Identifying and encouraging the formation of more spin outs and improving the level and consistency of support available to spin outs.
	Accelerator	Support the creation of an entrepreneurial ecosystem and promoting better industry awareness, participation in and investment in spin-out activity.
	Hire of Incubation Space	Making more space available to accommodate early stage spin outs.
	IP Licensing	Widening access to assets and reducing the cost of access to foster entrepreneurial activity.

Table 1; Definition of KPIs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CONCLUSIONS

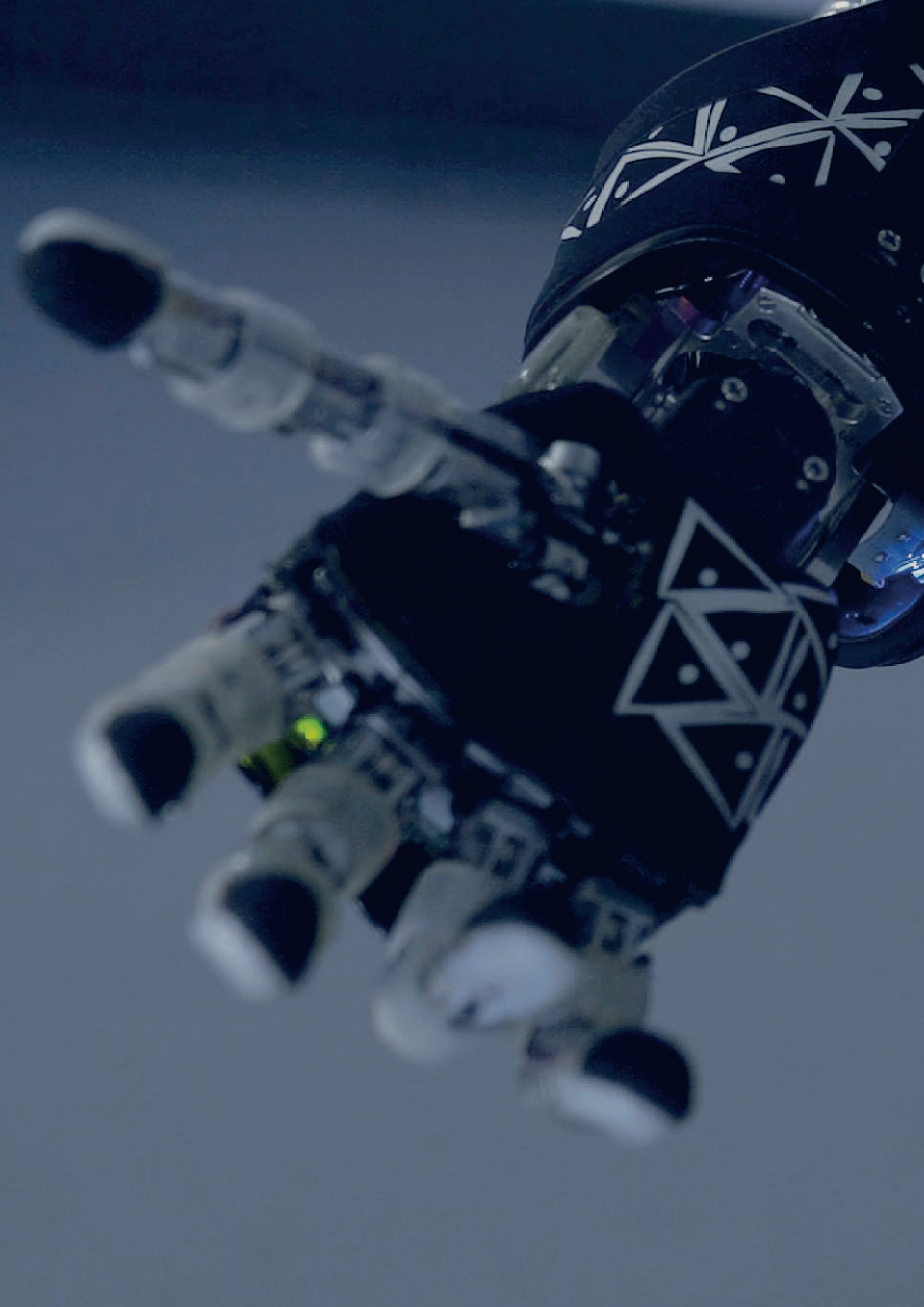
The creation of the National Robotarium presents a major opportunity for both universities to capitalise on their world-leading research in robotics and AI. In recognition of this we wish to go beyond the KPI levels set within the Edinburgh and South East Scotland City Region Deal. To achieve this it is necessary to develop what is a highly successful track record in the training of PhD students and low technology readiness level fundamental research through meaningful engagement with industry and the creation of an effective spin-out and start-up accelerator programme.

This development is currently a work in progress. Many of our research grants now support both fundamental research and translation activities and through this mechanism our relationships with industry is becoming deeper and stronger. A number of these projects are also developing commercialisation opportunities and our pipeline of spin-outs is growing as a consequence.

Essential activities we have yet to complete are the commissioning of the National Robotarium Building and an effective business development team to drive industry engagement. These matters are in hand.

The completion date for the building is March 2022 and by this time we are aiming to have the leadership team in post, along with a number of the supporting roles.

The project is therefore at a critical stage and we must ensure that we close off these essential developments in a timely manner to ensure we build on our successes to date and maintain our advantage in a very competitive marketplace.



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The National Robotarium is supported by £21 million from the UK Government and £1.4 million from the Scottish Government as part of the £1.3 billion Edinburgh and South East Scotland City Region Deal - a 15 year investment programme jointly funded by both governments and regional partners.

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