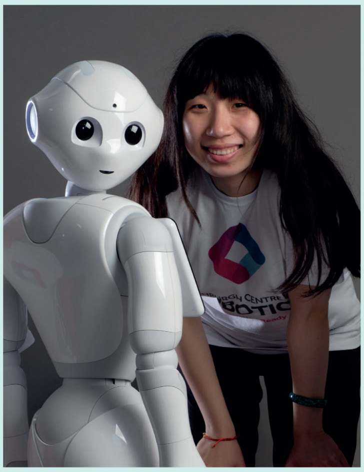
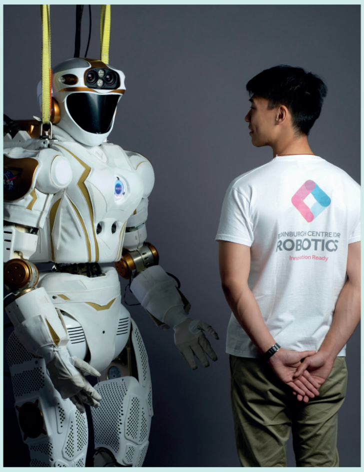
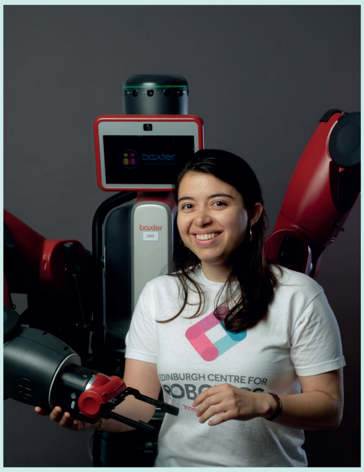
EDINBURGH CENTRE FOR
ROBOTICS
Innovation Ready







Annual Review 2018/2019

EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems

HERIOT WATT UNIVERSITY

THE UNIVERSITY of EDINBURGH

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Engineering and Physical Sciences Research Council

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To view our Annual Review online, please visit:
www.edinburgh-robotics.org/reports
This publication can also be made available in alternative formats on request.

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The Centre in Numbers 2014 -2019

Figures correct as at September 2019

TRAINING
EDINBURGH CENTRE FOR ROBOTICS

- 2 Centres for Doctoral Training
- 6 Cohorts
- 80 Students
- 50 Academics

RESEARCH
EDINBURGH CENTRE FOR ROBOTICS

- 64 Conference Proceedings
- 20 Journal Publications
- 19 Workshop Papers

Foreword

Welcome to our 2018/19 Annual Review highlighting key aspects and activities of students and staff in our EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems.

Our fifth year as a CDT has been exceptionally busy but rewarding. We recruited 17 students in the final intake of CDT RAS Phase 1, bringing the total number of students recruited over the course of this CDT to 72. We were delighted to receive confirmation that our bid to host a second CDT under the directorship of Professor Helen Hastie (HWU) and Dr Michael Mistry (UoE) was successful, with the new CDT getting off to a flying start with the recruitment of 14 high-calibre students. Ten of our industrial supporters are now providing financial support for thirteen studentships.

In addition to the welcome news of our successful bid to run another CDT, the creation of the UK's first National ROBOTARIUM reached a significant milestone on 17th December when its business case was approved by the Edinburgh and South East of Scotland City Region Deal Joint Committee. Discussions about the design of this new facility are now well under way with the building scheduled to open in 2021.

Students from the Centre hosted the third joint robotics CDT conference in Edinburgh in June 2019. Students from the Centres in Bristol and Oxford joined with the Edinburgh-based students for two days of keynotes, poster sessions, workshops and a Dragons' Den where students pitched their business idea to a panel of 'Dragons'. Innovation funding has now been made available to four teams of students to further develop research underway in the Centre. The student journal club continues to provide students with a forum where they can hone their presentation skills and explore areas of research they otherwise would not learn about. Calum Imrie from the 2015 cohort has done an amazing job running this for the last three years and we thank him for his efforts in setting up and managing this excellent student resource.

Congratulations are due to Professors Oliver Lemon and Verena Rieser who have been named as People to Watch in 2019 in the Digital List in FutureScot, a journal that reports on the digital technology sector in Scotland. The article recognises the team's research work in the area of AI, Machine Learning and Natural Language Processing and acknowledges that this has enabled Heriot-Watt University to be a top three finalist in the Amazon Alexa Challenge for two years in a row.

We have continued to welcome a number of high profile speakers to the Centre including Kim Hambuchen, Principal Technologist for Robotics, NASA; Robert Pieraccini, Director of Engineering at Google; Robert Deaves, Robotics System Architect at Dyson; Dave Ross, CEO, Agri-EPI Centre Ltd; and Samuel John, OtoJig GmbH.

Professor Katja Mombaur, Professor Stefan Schaal and Dr Andrew Fitzgibbon delivered inspiring keynotes at the Centre's fourth annual conference. Professor Mombaur provided an overview of her research into improved walking motions for humanoid robots. Professor Schaal outlined several topics that his research group had identified as important ingredients for autonomous robots, and Dr Andrew Fitzgibbon discussed his work in the development of real-world computer vision systems.

Students have been busy supporting outreach events including hosting the launch of a new Girlguiding Scotland Digital Activity Badge and the Edinburgh International Science Festival, where they showcased the Centre's current research, and ran demos and interactive sessions with collaborative robots and humanoid robots playing robot football.

The Centre has continued to collaborate with a range of organisations in academia and industry, including the running of a workshop to investigate how socially assistive robots and technology can be used to encourage healthy ageing. A new collaborative research project is underway with the International Institute of Neuroscience in Brazil to develop techniques that can inform new Parkinson's disease therapies.

We expect 2019/20 to be as busy as the year just finished with CDT student graduations, the start of building work on the National ROBOTARIUM and the first year of the new CDT RAS. We will be posting about these and other developments on Twitter @EDINrobotics. You can also keep up to day with our news by subscribing to our quarterly newsletter at www.edinburgh-robotics.org

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About us

EDINBURGH CENTRE FOR ROBOTICS
Innovation Ready

The Edinburgh Centre for Robotics (ECR) is a £120m joint venture between Heriot-Watt University and the University of Edinburgh, supported by EPSRC, Industry and the Universities.

It captures the expertise of 50 principle investigators of international standing from 12 cross-disciplinary research groups and institutes across the School of Engineering and Physical Sciences and the Department of Computer Science at Heriot-Watt University, and the Schools of Informatics and Engineering at the University of Edinburgh.

The Centre includes two consecutive EPSRC Centres for Doctoral Training (CDT) in Robotics and Autonomous Systems which train innovation–ready postgraduates, an £8m capital equipment facility, the £35m ORCA Hub and the £26m National ROBOTARIUM.

The Centre includes affiliated students engaged in related EU, EPSRC and UK-MoD research programmes, and local EPSRC CDTs in Data Science, Applied Photonics and Pervasive Parallelism as well as the NERC/EPSRC CDT in Next Generation Unmanned System Science.

The strategic aim of the Centre is to supply the urgent need for skilled, industry and market aware researchers in Robotics and Autonomous Systems. Interactions between robots, autonomous systems, their environments and people present some of the most sophisticated scientific challenges we must solve to realise productive and useful assistive or remote systems in our homes, workplaces and industries.

The Edinburgh Centre for Robotics is training a new generation of researchers to take a key role in solving such problems. These innovation-ready PhD students are being prepared to enter, lead and create the UK's innovation pipeline in this area for jobs and growth.

The Centre focuses on autonomous robot interaction with environments, people, systems and each other. We also research and develop work on Interaction Enablers, applying such fundamental theoretical methods to real-world problems, using real robots to solve vital commercial and societal needs.

Research is conducted using state of the art humanoid and field robotic platforms, in interactive spaces with fabrication facilities for soft embodiments, embedded microsensors and dedicated computing. Centre partners include companies in the energy, assisted living, transport, defence, medical and space sectors.

Management Structure

The Executive

The Executive is chaired by the Directors and is responsible for day-to-day operations of the Centre. Membership of the Executive is made up from the leadership teams from each University, Centre Administrators and student representatives. The Executive is responsible for student recruitment, progress and pastoral matters, public outreach, administering budgets, supervisor selection, organisation of annual conference and guest lectures, #Cauldron training programme, and commercialisation processes. It is also the first arbiter in the conflict resolution process with partners and students.

The Steering Group

The Steering Group consists of the Directors, senior academics from the Postgraduate Studies Committees at Heriot-Watt University and the University of Edinburgh, as well as a representative from industry (the Chair), EPSRC and from the RAS CDT student body. The remit of the Steering Group is to monitor the progress of the Centre, IP and licensing arrangements and relations with industry members, and to review and propose strategy and policy. The Steering Group will also act as final arbiter in the conflict resolution process for students and partners.

The External Advisory Board

The External Advisory Board reports to the Steering Group and comprises representatives from the Industry Members engaged with the Centre, plus two international academics and the Centre Management team. It will meet at least annually to monitor the work of ECR, provide strategic advice, support development of new business relationships and promote best practice. Members of the External Advisory Board serve in a non-executive capacity.

The Academic Board

An Academic Board involving all active supervisors and both Universities' representatives will also report to the Steering Group. Meeting annually, and chaired by the Directors, it will monitor the academic quality and delivery of both the taught courses and the research projects, and will deal with formal student progression.

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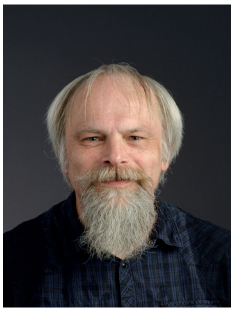

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EPSRC Centre for Doctoral Training

Robotics and Autonomous Systems

TRAINING
EDINBURGH CENTRE FOR ROBOTICS

Robots that can learn, adapt and take decisions will revolutionise our economy and society over the next 20 years. They will work for us, beside us, assist us and interact with us. It is estimated that by 2025 such advanced robotic and autonomous systems (RAS) could have a worldwide economic impact of $1.7 trillion to $4.5 trillion annually, with an emerging market value of €15.5 billion. The Edinburgh Centre for Robotics is advancing the UK's industrial potential in this revolution by producing a new generation of highly skilled researchers, trained to take a leading role. They are technically skilled, industry and market aware, and prepared to create and lead the UK's innovation pipeline for jobs and growth.

Our Doctoral students are part of a multi-disciplinary enterprise, requiring sound knowledge of physics (kinematics, dynamics), engineering (control, signal processing, mechanical design), computer science (algorithms for perception, planning, decision making and intelligent behaviour, software engineering), as well as allied areas ranging from biology and biomechanics to cognitive psychology. Our students specialise in one of these areas, gaining a deep understanding of technical aspect and theoretical foundations. They also receive broad training across these fields so as to meaningfully engage with a wide cross section of the robotics community.

Achieving impact with robotics also requires non-technical skills, for example an understanding of technology translation, creativity and entrepreneurial processes. These are an essential component of the CDT programme, captured in the #Cauldron training programme.

We offer around 15 studentships per year. Funding comes from EPSRC, Industrial Partners, Heriot-Watt University and the University of Edinburgh.

Key Benefits

EPSRC Centre for Doctoral Training

Robotics and Autonomous Systems

- Fully funded 4-year studentships covering tuition fees and maintenance at prevailing EPSRC rates and project related costs.
- Access to our world class infrastructure, enhanced through our £8m capital equipment facility and the £26m National ROBOTARIUM.
- Students benefit from supervision by academic experts from both institutions and graduate with a joint PhD from Heriot-Watt University and the University of Edinburgh.
- Excellent training opportunities, including some masters level courses in year one, supplemented by the #Cauldron programme which includes training in commercial awareness, social challenges and innovation.
- Innovation funding available to support development of early commercialisation prototypes.
- Opportunities for international placements in prestigious labs with industry or international partners.
- Opportunities to compete in international robot competitions (RoboCup Search and Rescue, SAUC-E Autonomous Underwater Vehicle Challenge Europe), European Robotics League, Amazon Alexa Challenge.
- Opportunity for competitive selection for funding from Cambridge IGNITE and MIT Sloan School of Management Entrepreneurship Programmes.

Academic Supervisors

We are indebted to the academic supervisors of all cohorts, who are fundamental to the success and direction of the research undertaken in the Centre.

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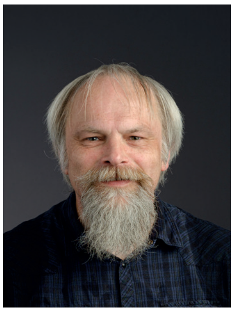

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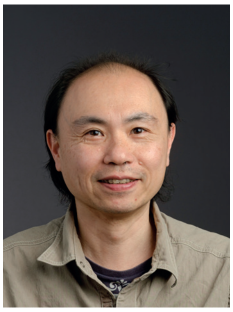

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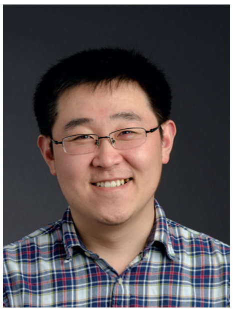

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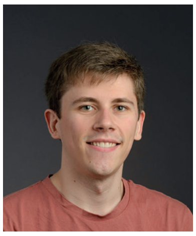

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Deep Learning of Human Activity in Audio and Video streams

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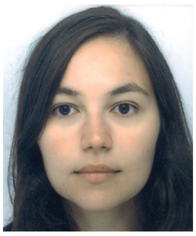
Situated Interactive Lifelong Learning



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Humanoid Visual Simultaneous Localisation and Mapping Fusing Proprioception

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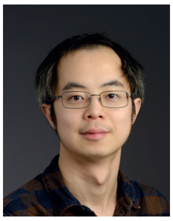
SMASH: One-Shot Model Architecture Search through HyperNets



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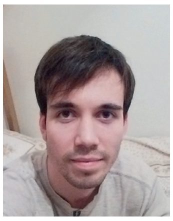
Human-Robot Collaboration and Robotic Dynamic Identification



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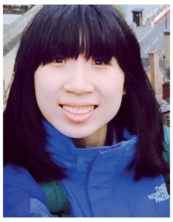
Intention Aware Human-Robot Collaborative Manipulation of Large Objects



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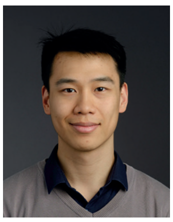
Real-time vision and tactile sensor fusion for object recognition



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Control and Learning of Versatile Legged Mobility on Complex Terrain

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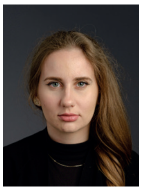
Towards an active meta-material for control and actuation of micro robots



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Explainable Artificial Intelligence (XAI)

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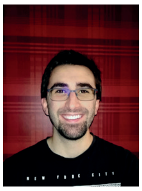
Memory acquisition and retrieval in the insect brain



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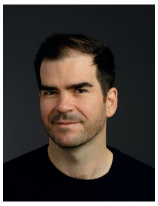

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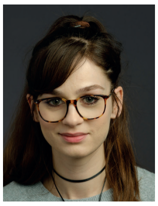

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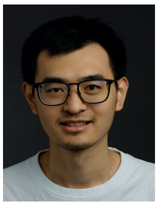

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Keyhan Kouhkiloui Babarahmati
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Lucas Kirschbaum
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Research Themes

RESEARCH
EDINBURGH CENTRE FOR ROBOTICS

Research in the Centre is underpinned by established bodies of theoretical work. We apply fundamental theoretical methods to real-world problems on real robots to solve pressing commercial and societal needs.

Research and innovation in the Centre focuses on new ways to make robots interact; with the **environments** around them, seeing, mapping, touching, grasping, manipulating, balancing; with **people**, understanding mood or emotion, using different sensory pathways including sight, touch, speech, gesture while predicting intentions and sharing plans; with **each other,** working collaboratively to achieve a task or capability: and with **themselves**, monitoring their self-health and performance.

We study the sensing, world modelling, planning and control architectures that can make these robots **persistently autonomous**, operating in unknown environments for extended periods adapting their plans in response to events to complete tasks. We also investigate **shared autonomy** where people and robots operate in highly synergistic ways to complete tasks.

We study nature to develop **bio-inspired** systems that sense and process data using the methods that have evolved in biological organisms. Finally, we also think about **ethical issues**, the decisions robots should and shouldn't be allowed to make, and the **regulatory** environments they work in.

	UNDERPINNING THEORY					
INTERACTION THEMES	Modelling & Estimation	Logic & Semantic Representation	Search & Optimisation	Learning & Adaptation	Bio-inspired Methods	Cognitive Modelling
1 **Environment Interactions:** Control, Actuation, Sensing, Planning, World Modelling	x	x	x	x	x	
2 **Multi-Robot Interactions**: Collaborative Decision Making, Swarming	x		x	x	x	
3 **People Interactions**: Affective Computing, Smart Spaces	x	x	x	x		x
4 **Self Interactions**: Condition Monitoring, Health Management, Prognostics. Persistent Autonomy	x	x	x	x		x
5 **Enablers**: Architectures and Embodiments, Validation & Verification	x	x	x	x	x	

Our Research Laboratories

Autonomous Agents Research Group

The Autonomous Agents Research Group is a research unit within the Centre for Intelligent Systems and their Applications. Research in the group is centred on the development of artificial intelligence and machine learning technologies toward the realisation of intelligent agents (such as software agents and robots) that can act autonomously to solve problems in complex dynamic environments. The group has a strong focus on problems of coordination and cooperation in multi-agent systems, in which multiple autonomous agents interact in a shared environment. Current research focuses on algorithms for multi-agent reinforcement learning and methods for inference and planning in dynamic multi-agent systems. The group also has experience in the development of autonomous agents applications, including in the areas of autonomous vehicles and cyber security.
http://agents.inf.ed.ac.uk

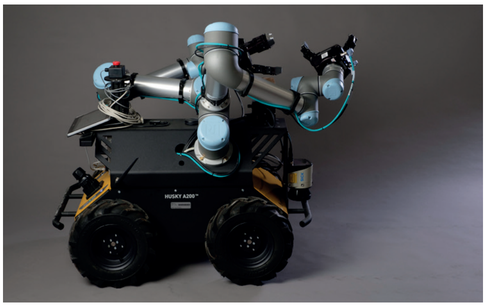
Bioinspired Robotics Laboratory

Bioinspired robotics draws on solutions found in nature for robotics problems, such as efficient locomotion control, effective navigation over short and long distances, and adaptive learning to flexible and noisy environments. In this lab we focus on understanding how insects, with their tiny brains, can support a range of capacities that easily outclass state-of-the-art robots. The lab carries out behavioural studies, in the lab and in the field, but principally develops computational models of the underlying neural mechanisms, which are tested on robot hardware. Recent projects include a neural model of odometry in the bee brain, tested on a flying robot platform; and an exploration of the learning capacities of maggots, which led to development of a novel learning algorithm that has proved effective on several benchmark robotics tasks.

Our Research Labs (cont)

Field Robotics Laboratories

Our research at Robotarium West focuses on enabling mobile robots and autonomous systems to understand real-world complex environments and achieve persistent autonomy in them. Research areas include robotic vision, simultaneous localisation and mapping (SLAM), autonomous navigation, 3D mapping and reconstruction, robot learning, computer vision and machine (deep) learning. The Lab has a Clearpath Husky mobile robot, a highly advanced and adaptable mobile robotics platform which is equipped with a variety of state-of-the-art sensors and manipulators (dual UR5 arms, LIDAR, Inertial Measurement Unit, stereo camera), to fulfil field missions even across challenging terrains. Our work on aerial swarm robots for autonomy and efficiency also addresses robot coordination tasks in critical activities.



The industrial applications of our research range from smart transport and delivery systems to outdoor inspection and emergency response challenges.
http://www.macs.hw.ac.uk/RoboticsLab/

Our lab at Robotarium East houses field robots designed to work in extreme and hazardous environments. It includes construction of mock-ups for the offshore and built environment infrastructure asset inspection sector based around the Total Argos Challenge mock up with ANYmal quadruped robot for sensor deployment. The lab is also equipped with fuselage co-assembly and manipulation mock up using a mobile Husky robot with multi arm manipulators for the airline assembly and maintenance, offshore asset inspection, and manufacturing sectors. The space also houses the Valkyrie humanoid robot (collaboration with NASA JSC) with additional mock-ups being constructed to replicate uneven terrain loco-manipulation tasks on the Mars mission. The locomanipulation platform is a modular scaffolding structure conceived to simulate industrial real-life environment in the robotic field-laboratory, which includes ramps and stairs that can be reconfigured to simulate a multitude of scenarios. This will be expanded with a high precision KUKA IIWA dual arm system including integrated force sensing for precise manipulation and safe human robot collaboration.

The setup will incorporate real-time Sigma.7 haptic devices with high fidelity for users to sense interaction forces and teleoperate better the torque controlled robots. Together with the VR/AR display and computing units, this will also provide intuitive and versatile controls to the robot during multi-contact and multi-modal operations in extreme and/or hazardous settings.All of this will be supported by a Vicon motion tracking system using 24 cameras along with a variable speed dual x-y-z heavy duty gantry system for support of dynamic locomotion on uneven terrain.

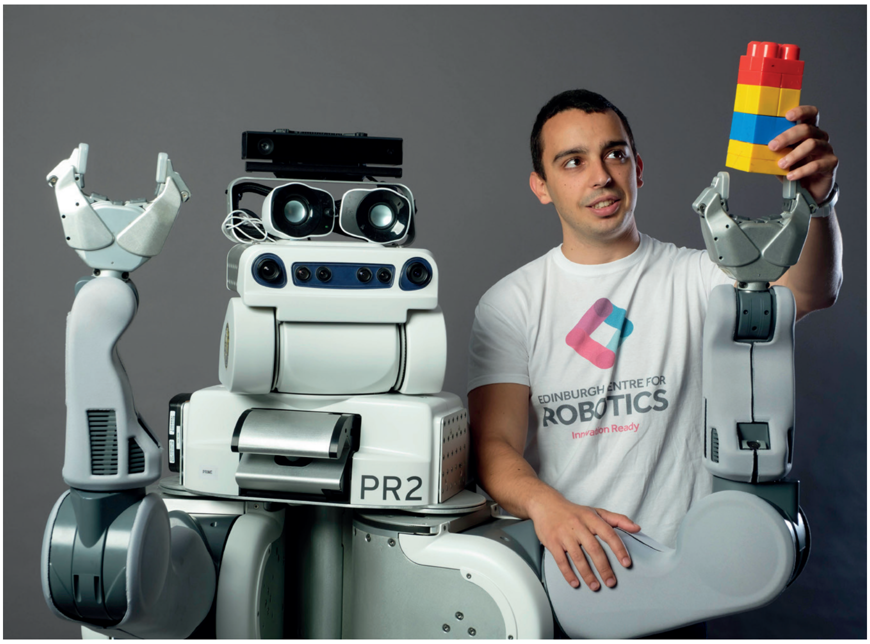
Gait Laboratory

This laboratory houses the Motek split treadmill with a force plate setup to carry out human lower limb prosthesis motion tests and Exoskeleton support experiments. Data capture is supported through a 12 camera Vicon tracking system along with wireless EMG and Xsens inertial tracking systems. Experiments here are run in collaboration with the NHS Astley Ainslie Hospital and the NHS Newcastle Gait labs, expanding our existing collaboration with local partners.

Independent Living Laboratory

The Centre avails of a 'Living-Lab" test-bed at Robotarium West, a fully sensorised 60m^2 home-like environment where our roboticists and computer scientists work alongside usability and health experts, psychologists, and people with assisted living needs, to co-design and test innovative solutions for healthy ageing and independent living. The research focus is on the combination of Robotics, AI and connected data systems, to assist humans and triage issues and also to facilitate communication and connectivity as part of personalised and connected social care practices. The laboratory participates in international initiatives promoting the certification and systematic evaluation and comparison of assistive service robots and user-centred, open innovation ecosystems for the integration of R&D results into real life communities and settings.
https://researchportal.hw.ac.uk/en/persons/mauro-dragone

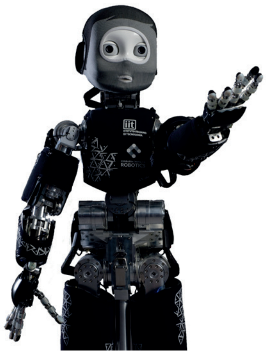
Our facility at Robotarium East houses living labs related to a hospital operating theatre mock up along with a reconfigurable setup for the following three scenarios: 1) surgical theatre assistance, 2) domestic home support, and 3) a factory co-assembly and support scenario. The three tasks can be switched by repositioning the 'equipment' in the work context while leaving the robots permanently fixed. PR2, Baxter and Kuka mobile robots will be used to study human robot collaborations in a hospital/care home setting, with the aim of delivering projects in the assisted living domain. The entire space will be sensorised with high density commodity cameras and activity log tracking systems. This setup will facilitate cutting edge machine learning research and big data approaches with the aim of developing new technology for assistive healthcare and smart cities.



Our Research Labs (cont)

Interaction Laboratory

Our research focusses on conversational AI, Natural Language Processing, and machine learning. We are developing intelligent interactive systems which can collaborate effectively and adaptively with humans, by combining a variety of interaction modalities, such as speech, graphics, gesture, vision, augmented reality and Natural Language. Our systems combine statistical and symbolic information processing, and we are developing data-driven machine learning approaches to build robust agents which can adapt autonomously in uncertain and dynamic interactions. These techniques are applied in a variety of domains, such as conversational assistants (e.g. Alexa, Siri etc), conversational search, emergency response, technology enhanced learning, healthcare informatics, and human-robot interaction (HRI).



We evaluate the performance of our models and algorithms both in simulation and in trials with real users. The Interaction Lab was one of only three teams to reach the finals of the Amazon Alexa Challenge, both in 2017 and 2018. We lead the human-machine interaction work on the EPSRC ORCA Hub for interacting with robots and autonomous systems in remote, hazardous environments.

Our projects include the H2020 MuMMER project, which focuses on interactive human-robot navigation around large indoor spaces such as shopping malls, and the H2020 SPRING project on social robotics for elderly care. Both of these projects also entertain and inform users via our Alexa challenge system.

http://www.macs.hw.ac.uk/interactionlab/

Ocean Systems Laboratory

This is a multidisciplinary science and engineering research centre that innovates, applies and teaches world class advances in autonomous systems, sensor modelling/processing, and underwater acoustic system theory/design for offshore, marine science, renewable energy and security applications.

©ORCA Hub

In Autonomous Systems, we have developed novel planning, obstacle avoidance, world modelling, operator dialog and visual servoing methods for Autonomous Underwater Vehicles and integrated them within open system architectures.

In Sensor modelling and analysis, novel navigation algorithms have been developed sharing information from multiple sensors. Model-based detection and classification algorithms have been successfully developed and trialled seeking mine like objects, seabed trawling impact and marine mammals in acoustic and video data. Our method has always been to have a three point approach to research problems by linking theoretical analysis, software simulations and experimental validation. Our tank facilities and vehicles enable us to validate the theory and simulation findings in real experiments.

http://www.oceansystemslab-heriotwatt.com

RAS Rapid Manufacturing and Design Studio

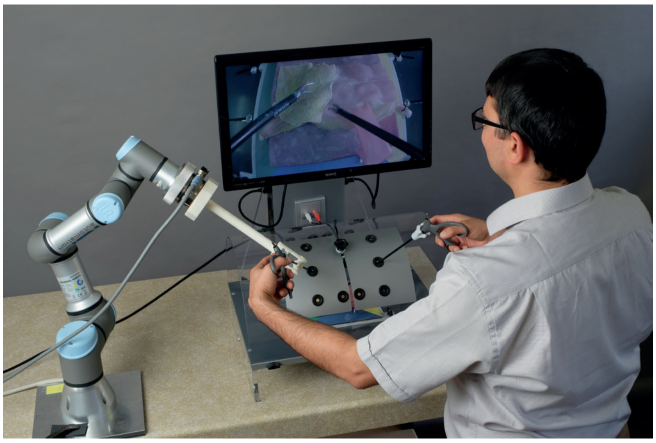
This facility (RMDS) encourages innovation and creation facilitated by digital and collaborative manufacturing tools. The Maker approach brings concepts and scientific principles to physical realisation facilitated by VR/AR, haptics, optical tracking, 3D scanning, 3D printing and laser cutting equipment. Besides research in digital manufacturing, concurrent engineering, collaborative design and review systems, we also research its associated human factors. RMDS has researched and implemented interactive systems using brain control, cyber-physical systems and body-area networks. RMDS is currently involved in an EU H2020 project to design and develop highly interactive mixed reality training environments. Supported by a bespoke multimodal data capture and synchronisation framework RMDS can offer innovative, versatile and comprehensive solutions in the area of knowledge/security/asset management, operational training and assessment, including functional art.
https://www.hw.ac.uk/schools/engineering-physical-sciences/institutes/mechanical-process-energy-engineering/rapid-manufacturing-design-studio-rmds-.htm

Robotic Micromanipulation and Microassembly Laboratory

The Robotic Micromanipulation and Microassembly Laboratory (RMML) develops techniques and solutions for fabrication and manufacturing of microdevices, microsensors, microsystems and microrobots. The capabilities are based on two decades of research in microsystem technology, especially methods and processes of microscale bonding and joining for interconnection, integration and packaging of sensors and microsystems. The current activities include the development of microgrippers which have been used to demonstrate assembly of 3D microstructures with an industrial partner. In an EPSRC funded project, we are developing microassembly methods for high temperature sensors and electronics capable of operation beyond 300°C. The research and knowledge have been transferred to postgraduate teaching in the EU funded Erasmus Mundus Joint Master Degree (EMJMD) Programme in Smart Systems Integration (https://ssi-master.eu/)

Skill Assistance Laboratory

The research activities in this Lab include physical human-robot interaction, assistive robotics, skill assistance, mechatronics design, medical robotics, walking robots, and machine learning. Specifically, our research has been focussed on identifying what "skill" is in manipulation tasks, such as manual-welding in industry and laparoscopy in medicine, through analysing data of novice versus professional subjects in four different modalities: trajectories of tool movement, robotised measurement of mechanical hand impedance, EMG recording of arm muscle activities, and near-infra-red spectroscopy recording of cortical brain activity. These data are analysed to find out the patterns of muscle activity that relate to the level of human skill. Brain activity monitoring provides a path-way to identify the skill level of subjects through criteria that cannot be consciously manipulated by the trainees. This might prove to be useful as a basis for making objective assessments and ultimately for providing individualised assistance in a variety of human-robot cooperative tasks.



https://researchportal.hw.ac.uk/en/persons/mustafa-suphi-erden

Our Research Labs (cont)

Strategic Futures Laboratory

Our research focuses on the use of AI tools to provide strategic overviews of large repositories of unstructured documents in order to aid high-level, evidence-based, decision making. We use advanced machine learning and visualisation approaches to provide intuitive, hierarchical maps of large to vast document sets. Statistical data and easy drill-down are also provided for deep exploration, quantitative analysis and automated decision making. Examples of use include providing strategic level comparison of national UK, US and EU research portfolios (circa 200,000 projects), comparing strengths and complementarities of eight sister organisations, and analysing trends in free of financial transactions.
http://strategicfutures.org

Virtual Reality Laboratory

High fidelity capture of human motion for work in collaboration with computer graphics and animation companies is carried out in this space which will host a range of cutting edge 3D real-time motion sensing and tracking capabilities. A 20+12 camera Vicon system is installed in addition to a more specialised motion capturing system with advanced software for tracking multiple subjects at the same time as well as hand gesture tracking. The lab also includes a high-framerate 3dMD3D body scanner and facial motion tracking system, and Oculus Rift AR/VR displays. This facility will focus on state of the art animation, graphics, and augmented reality with applications to robotics, construction, remote inspection, entertainment, and simulation and training for both research and the industry.

Smart Systems Laboratory

Our global society is placing increasing demands on its critical infrastructure, systems that deliver vital services such as energy, transportation, telecommunications, food and water, the built environment and healthcare. The systems within these sectors are increasingly complex and interdependent, interacting on a global scale. This complexity is required for efficient operation, but also makes systems more susceptible to cascading failure under stress.
The Smart Systems Group (SSG) believes we must transform data into actionable information and utilise this insight to create innovative, data informed, Smart Systems that can assess, adapt and respond to dynamic conditions. Our multidisciplinary team with expertise in data analysis, artificial intelligence, prognostics, manufacturing, energy systems and sensing technologies, are focused on the design, manufacture and characterisation of transformative Smart Systems.
Continuity of service from critical infrastructure and technology as a service trends are fuelling global demand for Smart Systems across all sectors of industry and services to society. We work with a global network of academic and industrial partners to deliver the flexibility, resilience and sustainability, our global infrastructure requires.
https://smartsystems.hw.ac.uk

Student Research Outputs

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Selected projects from across the Centre 2018/19

P_{40} **Using Causal Analysis to Learn Specifications from Task Demonstrations**
Supervisor: Dr Subramanian Ramamoorthy
PhD candidates: Daniel Angelov, Yordan Hristov

P_{42} **Cooperative Surveillance Missions using UAV Swarms**
Supervisors: Dr Patricia A Vargas, Dr Mauro Dragone
PhD candidate: Hugo Sardinha

P_{44} **Asset Management in Subsea Power Cables**
Supervisors: Professor David Flynn, Dr Keith Brown
Research Associate: Wenshuo Tang

P_{46} **Shared Autonomy in Dynamic Environments**
Supervisor: Professor Sethu Vijayakumar
PhD candidate: Christopher E Mower
Industrial Sponsor: Costain

P_{48} **Comparing Metrics for Robustness Against External Perturbations in Dynamic Trajectory Optimization**
Supervisor: Professor Sethu Vijayakumar
PhD candidate: Henrique Ferrolho
Contributors: Wolfgang Merkt, Dr Carlo Tiseo

P_{50} **Task-based Constrained Dynamics for Planning Robot Motions with Contacts**
Supervisors: Dr Mustafa Suphi Erden, Professor Sethu Vijayakumar
PhD candidate: João Moura
Research Associate: Dr Vladimir Ivan

P_{52} **Asset Inspection, Safety Compliance, Radar Inspection, Prognostics, Defect Identification**
Supervisor: Professor David Flynn
Research Associate: Jamie Blanche

P_{54} **Non-stop manipulation of moving targets using mobile collaborative robots and shared autonomy**
Supervisor: Professor Sethu Vijayakumar
PhD candidate: Wolfgang Merkt
Research Associate: Dr Vladimir Ivan

P56 **Online System Identification from Video for Robotics Applications**
Supervisors: Dr Subramanian Ramamoorthy, Dr Kartic Subr
PhD candidate: Martin Asenov

P58 **Pilot of the Future: Effectiveness of Sensory Modalities in a Multi-Modal Interface for Varying Task Complexity**
Supervisor: Dr Zhibin Li
PhD candidate: Eleftherios Triantafyllidis

P60 **Task Allocation Strategy for Multi-Vehicle Systems in the Underwater Domain**
Supervisors: Dr Ron Petrick, Professor Yvan Petillot
PhD candidate: Yaniel Carreno

P62 **A Wide Area Autonomous Telescope for Space Situational Awareness**
Supervisors: Dr Daniel Clark, Dr Yoann Altmann, Professor Yvan Petillot
PhD candidate: Mark Campbell

P64 **Partner Adaptive Dyadic collaborative Manipulation through Informed Hybrid Bilevel Optimization**
Supervisors: Professor Sethu Vijayakumar, Dr Michael Gienger
PhD candidates: Theodoros Stouraitis, Iordanis Chatzinikolaidis

P66 **Disentangled Relational Representations for Explaining and Learning from Demonstration**
Supervisors: Dr Subramanian Ramamoorthy, Professor Alex Lascarides
PhD candidates: Yordan Hristov, Daniel Angelov

Research Area: Human Robot Interaction

Using Causal Analysis to Learn Specifications from Task Demonstrations

Supervisor: Dr Subramanian Ramamoorthy
PhD candidates: Daniel Angelov, Yordan Hristov

Objectives

Learning models of user behaviour is an important problem that is necessary in many application domains involving extended human-robot interaction. In this work we show how to learn a generative model for distinct user behavioral types, extracted from human demonstrations, through enforcing clustering of preferred task solutions within the latent space. We use this model to differentiate between user types and to find cases with overlapping solutions. Moreover, we can alter an initially guessed solution to satisfy the preferences that constitute a particular user type by backpropagating through the learned differentiable model. An advantage of structuring generative models in this way is that it allows us to extract causal relationships between symbols that might form part of the user's specification of the task, as manifested in the demonstrations. We show that the proposed method is capable of correctly distinguishing between three user types, who differ in degrees of cautiousness in their motion, while performing the task of moving objects with a kinesthetically driven robot in a tabletop environment. Our method successfully identifies the correct type in 99% [97.8 - 99.8] of the cases, which outperforms an IRL baseline. We also show that our proposed method correctly changes a default trajectory to one satisfying a particular user specification even with unseen objects. The resulting trajectory is shown to be directly implementable on a PR2 humanoid robot completing the same task.

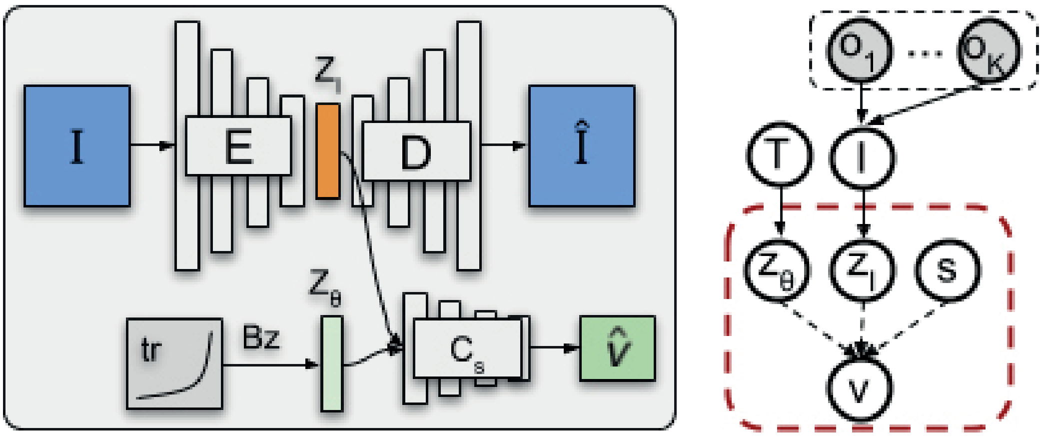

Figure 1: Overview of the framework.
Left: The model attempts to infer the validity of a trajectory - tr and an image I representing the scene, based on some predefined specification s. We encode the trajectory as a Bezier curve and use a latent representation of the image as the state space of our model. This allows us to backpropagate a learned specification and track the gradients that show how a trajectory needs to be changed to be valid under the new conditions.
Right: A structure causal model of the task. The specification model works with the nodes in red. This gives us the opportunity to intervene in the world by placing different objects in the scene and estimate the causal impact they have on the validity of the trajectory.

Approach and Results

We present a method for introspecting in the latent space of a model which allows us to relax some assumptions commonly required with alternate approaches, and more concretely to:

- find varied solutions to a task by sampling a learned generative model, conditioned on a particular user specification. We can perform this by minimizing a beta-VAE and classification loss.
- backpropagate through the model to change an initially guessed solution towards an optimal one with respect to the user specification of the task.
- build a causal model describing the implicit feature preferences in the demonstration by performing interventions, given the key environmental features.

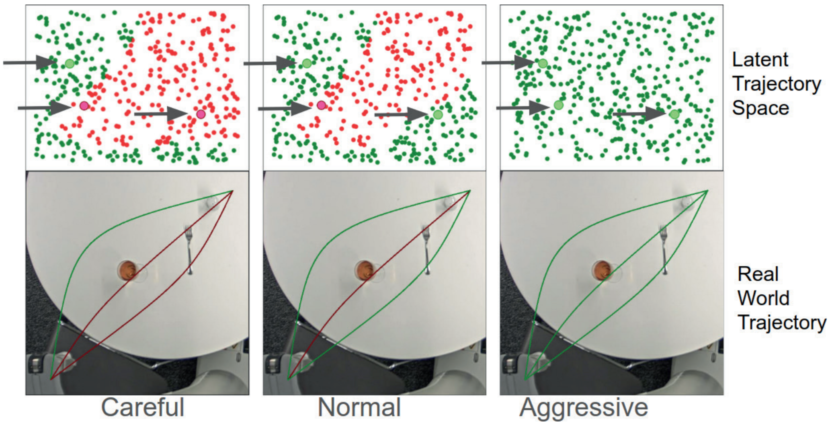

Figure 2: The table-top setup with 3 different demonstrator types and 3 trajectories highlighted in the scene and in the latent space. Green trajectories are valid and red - invalid.

Our method finds the optimal number of demonstrations per scene in our table-top navigation experiment (as depicted in Fig. 2) to accurately predict the validity of a trajectory and a world configuration under some latent expert specification. We further show that it is possible to use the gradients from the model to change the validity of a trajectory.

Impact

This work is supported in part by a Turing Institute project on Safe AI for surgical assistance. Our work aims to enable the causal learning of specifications of how people perform tasks and give insight into their attention mechanism.

Future Work

In this work we present a method for finding the specification that can be learned from expert demonstrations. This can be used to learn policies parameterized by different demonstrator types. We can use this parameterization to create hierarchical reinforcement learning policies that are safe [2] and allow to combine a diverse set of policies [3].

Publications

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Research Area: Swarm Robotics

Cooperative Surveillance Missions using UAV Swarms

Supervisors: Dr Patricia A Vargas, Dr Mauro Dragone
PhD candidate: Hugo Sardinha

Objective

The aim of this work is to increase the effectiveness of an aerial swarm system for cooperative surveillance missions. Designing efficient surveillance strategies in distributed aerial systems is of paramount importance in a variety of tasks such wildfire detection, industrial inspection or pollution monitoring. A key aspect of these problems is, not only to survey a given domain, but to ensure that reliable data is gathered. In this regard, it has been noted that using simple and inexpensive sensors performing multiple simultaneous readings of the same space is actually more cost effective that larger, heavier and more expensive sensors.

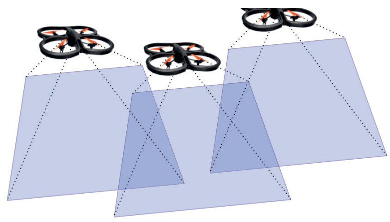


Figure 1: Example of overlapping sensing regions for 3 ar-drones

To tackle this issue, the current work proposes a hybrid strategy between the traditional concepts used in the coordination of artificial swarms and a stochastic component to enable the swarm with the capability of avoiding long-term local searches, while maintaining a meaningful overlapping of sensed regions.

Approach

It has been noted by mathematicians that a formal model can be derived that explains the motion of many natural systems in search for food/prey. It has been recorded that these collectives follow a *run-and-tumble* motion. This behaviour alternates with some probability between two distinct phases: *the tumble*, which refers to a seemingly random local search, much like the random walk known in many engineering applications; and *the run*, which refers to a long straightforward motion, allowing the agent to explore a more distant section of the domain. This process is known in the literature as *Lévy Walk*. A single agent's behaviour is controlled by parameter μ, belonging to]1, 3[, which imposes the length of each walk before a random change of direction, illustrated in Figure 3. Our method seamlessly integrates this exploratory behaviour with the *flocking* concept for coordination. Figure 3 highlights the differences between a coordi nated system and an uncoordinated one.

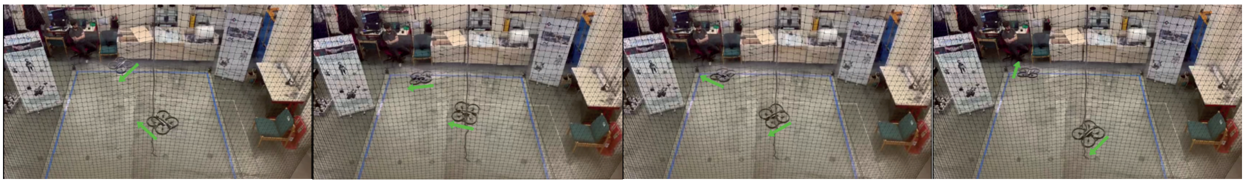
(a) μ = 1.2 (b) μ = 2.8

Figure 2: Trajectories of one agent with different μ values.

Figure 3: Swarm trajectories using simple avoidance mechanism (a) and the flocking concept (b).

Results

To test our method both simulation and real-world experiments were conducted in a grid-like domain. The grid is partitioned into tiles, and we assess the performance by the number of tiles sensed simultaneously by 2 drones. We compare these results with a different approach where the only interaction between agents is avoidance, to highlight the benefits of coordination. Furthermore, we also plot the probability distribution of the number of cells sensed by 2 drones simultaneously over the course of the experiments. Figure 4 exemplifies this comparison.



(a) **(b)** **(c)** **(d)**

(e) **(f)** **(g)** **(h)**

Figure 4: Trajectories of 2 ar-drone using only avoidance (a)(b)(c)(d) and our proposed model (e)(f)(g)(h)

Future Work

In the short-term, future work will focus a sensitivity analysis of the starting conditions such as the number of drones and size of the domain. On medium- term it will focus on variations of the *Lévy Walk* concept such as inertial motion, where the change of orientation is not purely random but biased towards the current heading. Furthermore, future work will also include a point-centric analysis where points of interest are scattered across the domain and the effectiveness of the system is measured not only on area covered but also on the number of points found.

Impact

This work has shown the superiority of our purposed model to address coordination and exploration using a swarm of aerial vehicles, while maintaining overlapping sensing regions. An extended version of these results has already been submitted as a conference paper, and is expected to be published shortly.

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Research Area: Asset Health Management

Asset Management in Subsea Power Cables

Supervisors: Professor David Flynn, Dr Keith Brown
PhD candidate: Wenshuo Tang

Objective

Subsea power cables are critical infrastructure which support the transfer of energy across networks and from offshore generation into the mainland. In the current practice of cable asset management, existing monitoring systems focus on electrical condition monitoring and therefore, do not account for over 70% of subsea cable failure modes associated with abrasion, corrosion and third-party impacts. In this research we look to the creation of a fusion prognostics model of the cable to support intelligent asset management and planning of subsea cables. Integrity predictions utilise offline and online data, along with a physics of failure model to predict cable remaining useful life (RUL). To improve the accuracy of this model we are also demonstrate the feasibility of using new data from low frequency sonar analysis via AUV deployment.

Approach and Results

We are proposing a fusion prognostic model for subsea cable inspection, lifetime prediction and health management, employing the offline multi physical model and the state-of-the-art low frequency sonar techniques for real time verification with AUV.

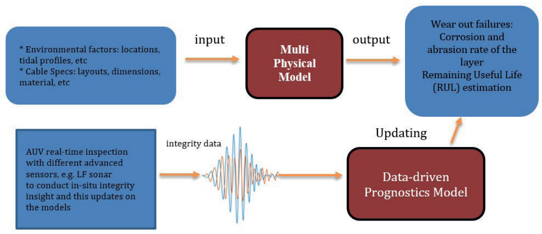

Figure 1: Fusion prognostic model workflow

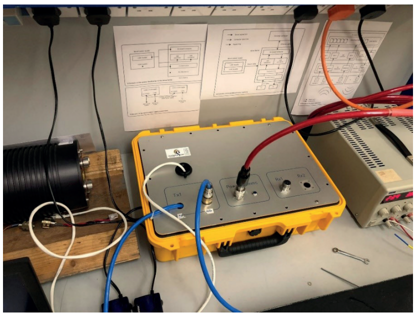

Figure 2: Wideband sonar scanning system

As demonstrated in Fig.1, the offline physical model provides an initial estimation of where faults may be. The role of the sonar and other sensors in AUV provides verification when it is employed for inspection. Finally, the data-driven model will update the latest integrity analysis results based on the field data collected. First, physical models have been developed to simulate the process where common cable failure modes lead to cable damage, such as abrasion and corrosion. In addition, multi-physics modelling techniques have been used to model cable displacement and scouring, with different environmental condition profile input. Furthermore, Sonar System and cable life cycle testing: The Low Frequency Sonar technologies is used to enhance lifetime prediction accuracy. Specifically, wideband sonar techniques (Fig 2) is manufactured to obtain integrity echo data from subsea cables with different specs or at different degradation level. We side scanned the cables and try to recognise common pattern, which corresponds to certain cable characteristics such as difference of inner structures and degradation levels.

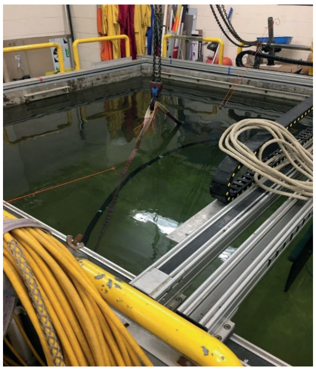

Figure 3: subsea cable echo data collection

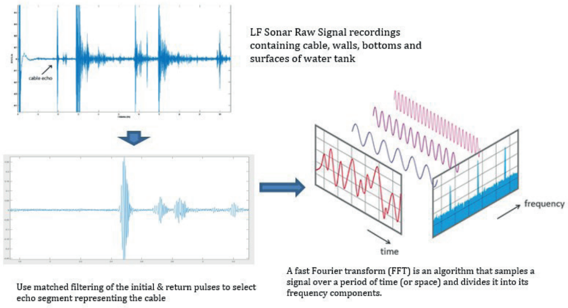

Figure 4: Bio-sonar raw data pre-processing steps

In this work, we applied machine learning techniques for the binary cable classification task, and the cables we choose are No.3 and No 4. The two cables resemble each other in physical characteristics such as diameters, however they have different degradation levels. As a first step we applied the feasibility of Support Vector Machine, Logistic regression and Convolutional neural network to train our classification model. The result is satisfied and is shown below in Table 1.

Classification Classes	No. of training data	No. of test data	SVM Accuracy (%)	Logistic Regression Accuracy (%)	CNN (%)
Cable 3 and 4	33	66	95.3±1.5	92.8±2.3	98.1±1.9

A fusion operational decision support system will be implemented to integrate these different physical failure models, in-situ inspection data from sonar, AUV inspection mission planning and data analysis results into a holistic subsea cable condition morning platform with more accurate remaining useful life prediction capability.

Impact

This is the first study about subsea cable integrity analysis and lifecycle prediction combining state of the art sensing technology and data driven approach. It is also the first attempt of a fusion prognostic system to integrate different multi physical models of subsea cable, in-situ inspection data from sonar, AUV inspection mission planning, and data analysis results. This holistic subsea cable condition morning platform will be more efficient and accurate at subsea cable maintenance and remaining useful life prediction. The outcomes of the analysis can support cable manufacturers, offshore operators and utility companies to accurately assess the life expectancy of their cabling systems from design, to deployment and lifecycle management.

Future Work

For future work, we will apply state-of-the-art machine learning algorithms on the data from accelerated lifecycle testing. Specifically, to distinguish echo response data from lifecycle with different levels of degradation; and to distinguish echo data obtained from different underwater conditions. In addition, we also conduct accelerated life cycle testing by manually introduce controlled stages of corrosion and abrasion to the cables. This enables the bio-sonar to obtain integrity data from various stages of cable degradation.

Publications

Integrity Analysis Inspection and Lifecycle Prediction of Subsea Power Cables, Wenshuo Tang, Keith Brown, David Flynn, Hugues Pellae. IEEE Prognostics and System Health Management Conference 2018, Chongqing

The Application of Machine Learning and Low Frequency Sonar for Subsea Power Cable Integrity Evaluation, Wenshuo Tang, David Flynn, Keith Brown, Xinyu Zhao, Robu Valentin, IEEE Oceans 2019, Seattle.

The Design of a Fusion Prognostic Model and Health Management System for Subsea Power Cables, Wenshuo Tang, David Flynn, Keith Brown, Xinyu Zhao, Robu Valentin, IEEE Oceans 2019, Seattle.

Research Area: Shared Autonomy, Industrial Robotics

Shared Autonomy in Dynamic Environments

Supervisor: Professor Sethu Vijayakumar
PhD candidate: Christopher E. Mower
Industry sponsor: Costain

Objective

Teleoperation of industrial manipulators is generally repetitive and requires high levels of concentration and manual dexterity. Excessive cognitive loads invariably lead to fatigue that can become dangerous for humans in shared workspaces with manipulators, as in Fig. 1. This danger is prevalent in the construction sector seen by having the highest levels of incidents involving fatalities per annum in the United Kingdom.

Figure 1: Concrete spraying application in a freshly excavated tunnel using a 5-DoF concrete spraying unit. Image provided by Costain Laing O'Rourke Joint Venture.

There are several factors that negatively impact direct teleoperation, such as: 1) inadequate or unintuitive interfaces, 2) coarse and highly variant input commands from the operator, 3) poor observability or the task by the operator, 4) a limited supply of skilled workers, 5) deficient fidelity of the link between operator and the robot (for instance caused by network latency), and 6) operator fatigue due to high levels of concentration. The work here aims to address some of these limitations by determining appropriate modes of control for unskilled operators and computationally tractable methods to assist in teleoperation tasks that reduce the cognitive load on the human.

Approach

In the first piece of work, we analysed appropriate modes of teleoperation (defined by the space control commands are submitted and its dimensionality) for unskilled human operators performing a target acquisition task inspired by our main application domain, concrete spraying, as in Fig. 1. We provide an analysis of the various modes of teleoperation through an empirically driven investigation based on the well-known Fitts' Law. Fitts' Law was used because it provided fair comparison across tasks with varying difficulty. An extensive dataset of results was collected containing objective and subjective metrics. A multivariate analysis was conducted to compare two subsets of our participants based on personal habits we identified to effect performance. We also generalized Fitts' Law to two additional performance metrics inspired by the concrete spraying application. The data was collected from real-world experiments using the KUKA LWR robot arm, as in Fig. 2.

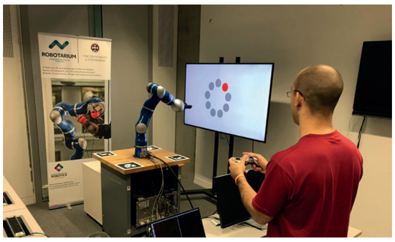

Figure 2: An operator controlling the KUKA LWR arm in our empirical study.

Our second piece of work proposed an optimization-based representation for shared autonomy that accounts for environment changes while remaining computationally tractable, by modulating the human input using the task/environment information within the same task space. We showed how our method can be applied to assist in two teleoperation tasks; a grasping task, and a spraying task. We implemented the method on a KUKA LWR robot arm. The proposed method blends human and autonomous reasoning within the same task space informed by real-time sensory data and can find solutions in computation times fast enough for real-time usage.

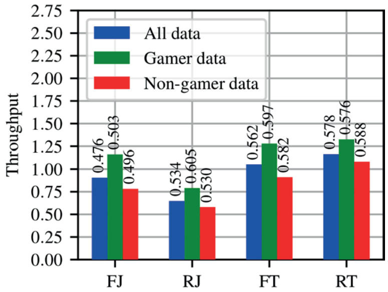

Figure 3: Throughput results, an estimate for task performance.

Results

In Fig. 3, we show a subset of our results from the first piece of work which demonstrates that highest performance was seen for the reduced task (RT) control mode of teleoperation. Additionally, we see that those we classified as gamers (i.e. those who regularly play computer games) were generally able to complete the task faster than those who were classified as non-gamers. The main conclusion of the work is that users performed better when submitting commands in lower-dimensional task spaces. Our data collected using subjective means also participant preferences tended to favour the RT mode.

We showed, among other experiments, in our second piece of work that our proposed shared autonomy method (input modulation) maintained computational tractability even for high numbers of collision points in the environment; see Fig. 4.

Future Work

In future work, we will develop methods that achieve high performance in manipulation tasks at the cost of only modest interactive effort on the part of the operator. To produce optimal robot motions while maintaining given movement constraints we aim to explore numerical optimization techniques. Such techniques often lead to large computation times; thus, the work will develop methods that maintain tractability of the algorithms leveraging human input to bias the solver towards certain local minima.

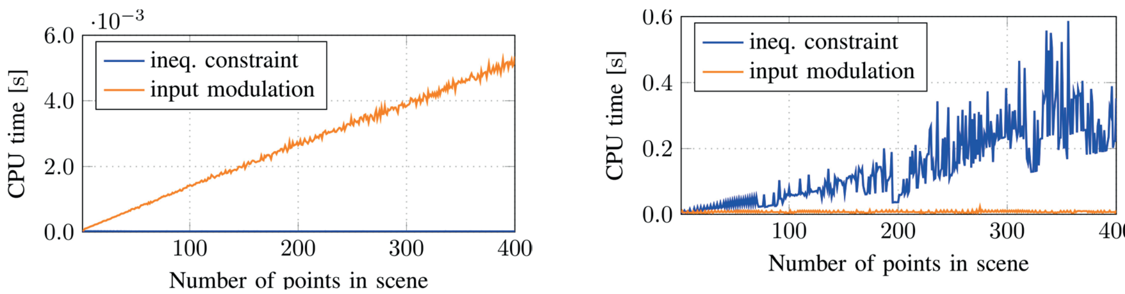

Figure 4: Completion time results plotted against number of points in the scene for (left) the setup phase, and (right) the solver phase for a shared autonomous spraying task.

Publications

Christopher E. Mower, Wolfgang Merkt, Aled Davies, and Sethu Vijayakumar, Comparing Alternate Modes of Teleoperation for Constrained Tasks, IEEE 15th International Conference on Automation Science and Engineering (CASE), Vancouver, BC, Canada, 2019. Video: https://youtu.be/SWWtT1vHnsM. Pre-print: https://arxiv.org/abs/1905.04428.

Christopher E. Mower, João Moura, Aled Davies, and Sethu Vijayakumar, [to appear] Modulating Human Input for Shared Autonomy in Dynamic Environments, IEEE 28th International Conference on Robot & Human Interactive Communication (RO-MAN), New Delhi, India, 2019.

Research Area: Trajectory Optimization

Comparing Metrics for Robustness Against External Perturbations in Dynamic Trajectory Optimization

Supervisor: Professor Sethu Vijayakumar
PhD candidate: Henrique Ferrolho
Contributors: Wolfgang Merkt, Dr Carlo Tiseo

Introduction

Dynamic trajectory optimization is a popular approach for generating optimal and dynamically consistent trajectories. In order to improve the robustness of planned trajectories, a wide range of metrics have been proposed for inclusion in the problem formulation. These metrics often try to maximize the system's manipulability [1], force capabilities [2], or remaining control authority. However, they come with an *increased computational cost* and their impact has not yet been *benchmarked* and *compared*.

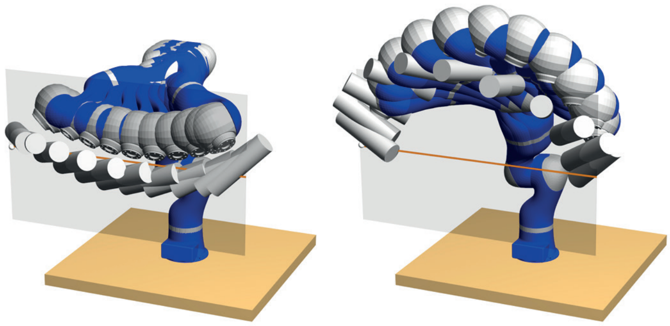

Figure 1:
Dynamic motions of a robot carrying a heavy payload.

The different geometric configurations along the trajectory empower the system with distinct force capabilities.

Objectives

The goal of our work is two-fold: (1) establish an assessment *protocol* and *benchmark* for the robustness of dynamic robot motions; and (2) augment the optimization problem for attaining trajectories more robust to *model errors* and *external disturbances*.

Approach

We ensure greater *control authority* margins for responding to errors at the control stage by explicitly taking into account robot-specific capabilities at the planning stage.
To this end, we:

1. Detail a *protocol* for quantifying the performance of dynamic trajectories;
2. Review and compare a number of previously proposed robustness objectives;
3. Propose a *novel* force polytope-based metric taking into account actuation requirements for gravity compensation and task achievement, the *residual force polytope*;
4. Open source a flexible dynamic trajectory optimization framework for evaluating different metrics and robustness objectives, along with our benchmark tools for *reproducibility*.

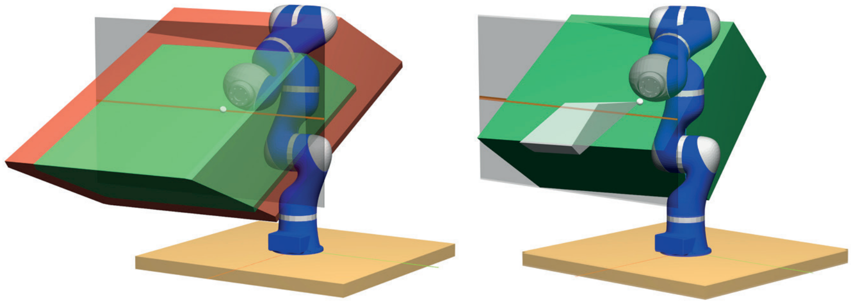

Figure 2:
Left: Shows the force polytope (in red) and the *residual force polytope* (in green).
Right: Shows the *residual force polytope* and its intersection with a force cone (in white).

Results

The data and results collected from the benchmark reflect the following remarks:

1. Concerning end-effector *task constraints violation*, polytope-based methods showed better performance under external disturbances but performed worse for model errors. However, provided an approximation for the perturbation direction was given *a priori*, polytope-based methods outperformed the other methods.
2. Concerning *realized mechanical work* and *actuation limit saturation*, polytope-based methods performed better for both model errors and external disturbances.

Impact

With this work, we aim to close a gap in the literature as many robustness metrics have been put forward in isolation, and yet, often without being benchmarked against other existing approaches. We also hope that open sourcing our framework and benchmarking tools will aid the community in developing new robustness objectives and comparing them with other approaches with more ease in the future.

Future Work

Polytope-based methods showed some benefits compared with other more simplistic metrics but they are computationally very expensive [3]. Regardless of technological advancements, opportunities of their deployment for time-critical applications currently remain challenging. However, they still carry significant value for *feasibility analysis* and *system design*, making them a compelling topic for further research.

References

[1] T. Yoshikawa, "Manipulability of Robotic Mechanisms", in *IJRR*, 1985.
[2] R. Orsolino, M. Focchi *et al.*, "Application of Wrench-Based Feasibility Analysis to the Online Trajectory Optimization of Legged Robots", *IEEE RA-L*, 2018.
[3] T. S. Motzkin, H. Raiffa *et al.*, "The double description method", in *Contributions to the Theory of Games*, 1953.

Publications

H. Ferrolho, W. Merkt, C. Tiseo, and S. Vijayakumar, "Comparing Metrics for Robustness Against External Perturbations in Dynamic Trajectory Optimization", in p. *arXiv e-prints*, arXiv:1908.05380, Aug. 2019. Online: https://ferrolho.github.io/research/publications/ferrolho2019comparing/

Research Area: Robot Dynamics

Task-based Constrained Dynamics for Planning Robot Motions with Contacts

Supervisors: Dr Mustafa Suphi Erden, Professor Sethu Vijayakumar
PhD candidate: João Moura
Research Associate: Dr Vladimir Ivan

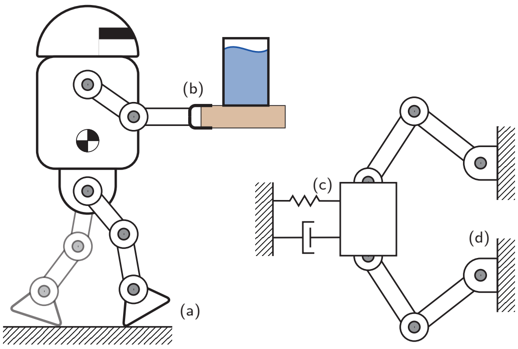

Figure 1: Illustration of different constraints imposed by the robot's surroundings or required behaviour. Examples are:
a) using contacts for bipedal locomotion; b) keeping the balance while executing a critical task such as holding a glass of water; c) having a compliant behaviour while following a given trajectory; d) and robots with closed kinematic loops.

Objective

The analysis, design, and motion planning of robotic systems often relies on its forward and inverse dynamics models. When executing a task involving interaction with the environment, both the desired motion task and the environment impose constraints on the robot's motion. For modelling systems, we need to incorporate these constraints in the robot's dynamic model. Fig. 1 illustrates some of those constraints where some of them are: rigid constraints, such as (a) contacts and (d) closed kinematic loops; and others are desired tasks/behaviours, such as (b) desired task motions and (c) compliant behaviours.

A very well-known methodology for incorporating motion tasks and compliant behaviours in the dynamics of a rigid-body system is through the Operational Space Formulation, originally proposed by Oussama Khatib. This formulation derives the dynamics of the robotics system in the task space by defining the task space inertia matrix M_X. Regarding rigid constraints, various robotics literature works rely on the Projection-based Dynamics approach proposed by Farhad Aghili. This approach consists in deriving the dynamics of the constrained robotics system in the configuration space, by defining the constrained inertia matrix M_C.

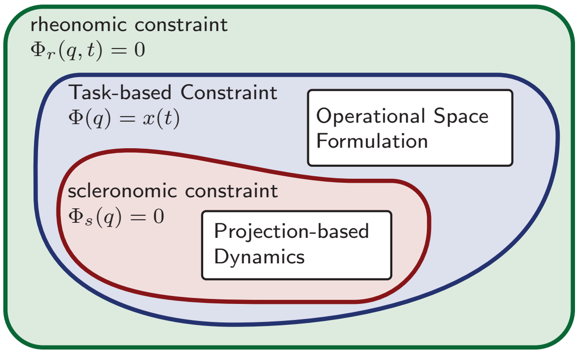

Figure 2: Diagram illustrating the categorization of two forward dynamic approaches regarding their underlying equality holonomic constraint. A rheonomic constraint is a time dependent constraint, a scleronomic constraint is a time independent constraint, and a task-based constraint is a time dependent constraint with decoupled dependence on the configuration q and time t

In this work, by defining a new class of Task-based Constraints, which essentially includes both task motions and rigid contacts, we prove the analytical equivalence between the Operational Space Formulation and Projection-based Dynamics approach. Fig. 2 illustrates the classification of those two dynamics approaches regarding their underlying equality constraint.

The Task-based Constraint Dynamics proposed in this study provides, therefore, a unified framework for dealing with both contacts and motion tasks which often require simultaneous control, as shown in Fig. 3. The finding of the equivalence between the Operational Space Formulation and the Projection-based Dynamics approach enables the comparison between studies based on each approach and can potentially lead to the transfer of methods and results from one approach to the other.

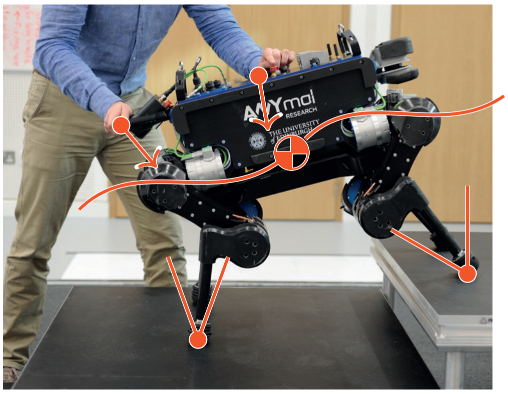

Figure 3: Example of application of the task-based constraint dynamics which allows modelling of both rigid constraints, such as contacts, and task motions, such as the motion of the robot's centre of mass, in a unified framework.

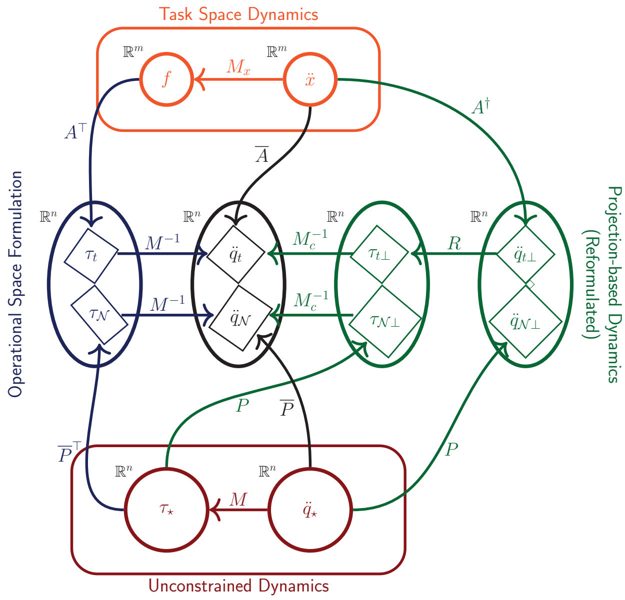

Figure 4: Diagram illustrating the mappings between different spaces, highlighting that both the Operational Space Forumulation and the Projection-based Dynamics approach result in an equivalent decoupling of the task acceleration and the null space acceleration.

Method and Results

Let M be the inertia matrix of a robotic system, and A be the Task-based Constraint Jacobian. We proved that

$$A^M = M_C^{-1} R A^+, \text{ and } P^M M^{-1} = M_C^{-1} P,$$

where A^+ is the pseudo-inverse of A, A^M is the inertia-weighted inverse of A, $P = I - A^+ A$ is the orthogonal projection, $P^M = I - A^M A$ is the inertia-weighted projection, I is the identity matrix, and $M_C = P M + R (I - P)$ is the constraint inertia matrix, for any R such that M_C is full rank.

A This result shows that using the orthogonal projection P in conjunction with the constraint inertia matrix M_C (Projection-based Dynamics) is equivalent to using the inertia-weighted projection P^M, famously employed in the Operational Space Formulation. Fig. 4 illustrates the previous equalities as their respective mappings between different spaces.

Future Work

Going forward, finding what are the particular cases or numerical procedures that highlight the advantages of each approach (Operational Space Formulation versus Projection-based Dynamics approach), both in terms of the computational speed and numerical errors, can lead to some impactful practical benefits resulting from using the Task-based Constrained Dynamics framework.

Publications

João Moura, Vladimir Ivan, Mustafa Suphi Erden, and Sethu Vijayakumar. Equivalence of the Projected Forward Dynamics and the Dynamically Consistent Inverse Solution. In Robotics: Science and Systems XV (R:SS), 2019. (Best Paper Award Finalist)

Research Area: Asset Integrity and Safety Compliance

Asset Inspection, Safety Compliance, Radar Inspection, Prognostics, Defect Identification

Supervisor: Professor David Flynn
PhD candidate: Jamie Blanche

Objectives

Robotic platforms represent an invaluable enabler for real time asset monitoring, providing access to harsh environments, which represent a risk to human safety, as well as reducing operational and maintenance costs. Robotic platforms must always ensure the safety of personnel and infrastructure, furthermore, human in loop experts need to trust the information fed back from these field deployed systems. A global bottle neck to beyond visual line of sight (BVLOS) operations in robotics, relates to their reliability within dynamic environments. Therefore, we have developed a research stream which is robot platform agnostic and use case agnostic, wherein, we use robust sensing technology that supports front end analysis and decision making. To avoid interference from ambient conditions and efficient run-time analysis, we have explored the application of Frequency Modulated Continuous Wave (FMCW) technology for asset integrity inspection and localisation in harsh operating environments. In this report we outline initial applications in structural health monitoring with respect to corrosion under insulation (CUI) for metallic structures and hidden defects within wind turbine (WT) blades, composite structures, via a remotely operated drone as well as an autonomous ground vehicle (Husky A200).

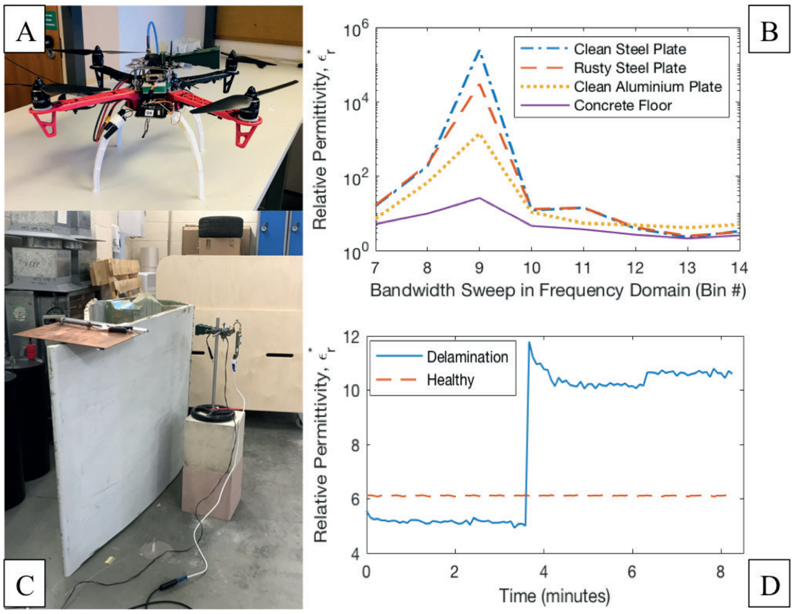

Figure 1A) Quadcopter 450 series with mounted K-band FMCW radar module. Utilised for successful CUI testing. **B)** K-band steel corrosion defect detection displayed as a relative permittivity measurement and in contrast to healthy baseline materials. **C)** Static mounted K-band FMCW antenna used to compile defect library within a wind turbine blade section. This blade section contains multiple internal delamination and structural defects. **D)** Dynamic result testing of WT blade shown in previous image. Blue solid line shows the contrast of water ingress within an internal glass fibre delamination feature (water added at 3 mins 40 sec). Red dashed line displays healthy baseline for reference.

Approach and Results.
This work has utilised two robotic platforms (a 450 series quadcopter in collaboration with University of Manchester with a maximum lift weight of 1600g and a Heriot Watt-based Husky A200 series wheeled robotic system with manipulator arms). A controller and K-band microwave radar module were mounted and tested for sensitivity to targets representing common failure precursors for offshore asset structures. This research has established the operational data telemetry requirements necessary for near to real time function and to inform on microwave radar sensitivity to corrosion defects, delamination and fluid ingress events within insulated and porous structures. This has enabled semi-autonomous robotic detection of CUI in polymer cladded pipeline structures and delamination features within wind turbine blade structures. This work is a continuation of research conducted by this group using K-band radar to detect pore space occupancies within porous geomaterials partially saturated with deionised water and kerosene, in addition to determining bulk permittivity values in room dry geomaterials, allowing for the detection of metals and other conductive constituent elements.

Impact
This work is well aligned with several on-going projects, including HOME offshore and the ORCA HUB. The framework being developed contributes to the non-destructive and non-contact characterisation of dielectric materials and contrasts in dynamic properties as a function of asset degradation and failure during operation, allowing for the efficient determination of maintenance schedules for O&G and renewable infrastructures. This technology has led to patents, high impact publications and media attention (BBC). This technology is being deployed in additional trials within the civil and nuclear sectors via the Heriot-Watt University spinout company MicroSense Technologies Ltd.
https://www.microsensetechnologies.co.uk
https://www.bbc.co.uk/news/uk-scotland-47004588

Future Work
These results are part of a programme of research aimed at de-risking the inspection of assets in offshore areas while simultaneously allowing for the quantification of defect magnitude via reference to a large library of tested defect modes. Robotic inspection acts as an augmentation tool for human inspection teams, allowing for quicker, safer and holistic inspection regimes for expansive offshore O&G and renewable assets. We aim to provide accurate defect sensing capabilities for BVLOS inspection platforms operating from both manned maintenance vessels or acting independently under the drone in a box paradigm of robotic deployment.

Publications
[1]J. Blanche, D. Flynn, H. Lewis, G. Couples, and R. Cheung, "Analysis of Geomaterials using Frequency Modulated Continuous Waves," presented at the Thirteenth International Conference on Condition Monitoring and Machinery Failure Prevention Technologies, Paris, 2016.
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[5] J. Blanche, "Frequency Modulated Continuous Wave Sensing for Static and Dynamic Material Analysis," PhD (unpublished), Institute of Signals, Sensors and Systems, Heriot-Watt University, Edinburgh, 2019.

Research Area: Shared Autonomy

Non-stop manipulation of moving targets using mobile collaborative robots and shared autonomy

Supervisor: Professor Sethu Vijayakumar
PhD candidate: Wolfgang Merkt
Research Associate: Dr Vladimir Ivan

Main Objectives

Regular inspection and condition monitoring is crucial to increase the lifespan of critical infrastructure and to prevent catastrophic failure. One prominent use case investigated in the ORCA Hub is the monitoring of remote off-shore assets. In this environment, inspection is both costly and dangerous.
Autonomous inspection involves tasks including navigation, detection of anomalies, and reading sensors such as pressure gauges. However, outside of existing sensing infrastructure, to holistically assess the condition of an asset new sensors need to be deployed or replaced.
Our objective is to deploy and reposition these sensors precisely and efficiently in the presence of disturbance and sensing uncertainty. Key hereto are efficient processes to stabilise the manipulation motion against external perturbation.

Approach

To enlarge the operational workspace of safe, collaborative robots, we employ a high-performance, high-payload, and high-speed omni-directional mobile collaborative platform. Its distinctive advantage is the high precision allowing joint control of the base and manipulator motion. This achieves an enlarged work area for precise task execution. It further allows us to carry out continuous manipulation effectively saving battery power from avoiding acceleration and deceleration resulting in increased efficiency.
This is achieved by transferring a concept widely applied in legged and humanoid robots, and to use non-linear optimisation based whole-body control.

Results

We validated the performance of our approach using a "chicken-head task". Here, the manipulator's end-effector is required to remain static in the work-space while the base reacts to disturbances. We evaluated this in the laboratory against ground truth using the ECR's VICON Motion Capture System and show an illustrative use case in Figure 2.

We also deploy our solution to place sensors without stopping on an industrial training facility (cf. Figure 1). Here, live sensing was used to automatically adjust the motion in response to locally sensed information.

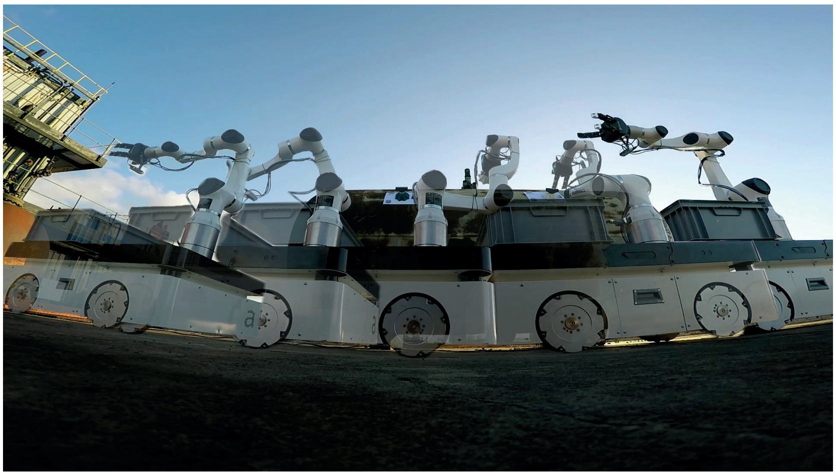

Figure 1: Continuous manipulation using whole-body control: an industrial IoT monitoring device is placed using live sensor feedback without stopping at the ORCA Trials at the Fire Service College in Moreton-on-Marsh.

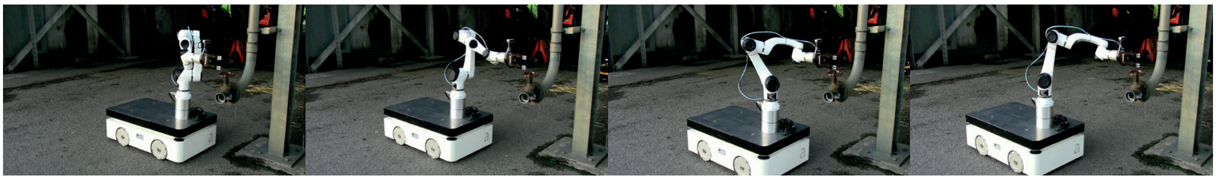

Figure 2: The chicken-head task on a rough outdoor surface carrying out a proposed scenario: manipulation of a static end-effector affordance while responding to disturbance with the redundancy of the omni-directional base. Here, the base follows a high velocity figure-eight target while the end-effector is to be kept static above the valve.

Impact

The robust inspection provided by this project impacts the industry and society on multiple dimensions: It decreases risk and increases safety by removing humans from hazardous processes (saving human lives). It also decreases the cost of inspection (economic) and reduces the risk of catastrophic failures (environmental).

In addition, the presented framework allows the rapid transfer of new algorithms developed in visualisation and simulation to real-world platforms. We showed that the high-performance whole-body control framework resolves discrepancies and challenges commonly found in other mobile manipulation platforms. We demonstrated the efficacy of this approach in performance evaluations as well as on a sensor placement task. This has resulted in a follow-on collaborative project.

Future Work

Together with one of the partners in the ORCA Hub, Imperial College, we are extending this work for automated contact-based corrosion testing of metal surfaces. Using the presented architecture, a novel induction-based sensor developed by Imperial College is deployed for a sensing task with live visual sensor feedback. Here, we use force torque information for aligning the sensor to curved surfaces and live sensing information for active sensing to get a full picture of the corrosion state of critical infrastructure. We will demonstrate this during the ORCA Field Trials in early October 2019.

Publications

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Research Area: System Identification, Perception

Online System Identification from Video for Robotics Applications

Supervisors: Dr Subramanian Ramamoorthy, Dr Kartic Subr
PhD candidate: Martin Asenov

Objectives

Robots performing tasks in dynamic environments would benefit greatly from understanding the underlying environment motion, in order to make future predictions and to synthesize effective control policies that use this inductive bias. Online system identification is therefore a fundamental requirement for robust autonomous agents. When the dynamics involves multiple modes (due to contacts or interactions between objects), and when system identification must proceed directly from a rich sensory stream such as video, then traditional methods for system identification may not be well suited. We propose an approach wherein fast parameter estimation with a model can be seamlessly combined with a recurrent variational autoencoder. We benchmark against existing system identification methods and demonstrate that Vid2Param outperforms the baselines in terms of speed and accuracy of identification, and also provides uncertainty quantification in the form of a distribution over future trajectories. Furthermore, we illustrate the utility of this in physical experiments wherein a PR2 robot with velocity constrained arm must intercept a bouncing ball, by estimating the physical parameters of this ball directly from the video trace after the ball is released.

Approach

We present a model that extends the Variational Recurrent Neural Network (VRNN). We add an additional loss term for encoder-decoder mapping from a given sensory input to physical parameters and states. We show that such a model can be trained with suitable domain randomization in simulation, and deployed in a real physical system. To illustrate the utility of this capability, we demonstrate this model on the task of intercepting a bouncing ball with a relatively slow moving robot arm and standard visual sensing.

Results

We observe that the proposed method can accurately infer different physical parameters, outperforming baselines from the literature. Our method can accurately estimate parameters with similar effect on the dynamics (gravity and air drag), as well as parameters whose effects are not observed until the end of the trajectory (rolling coefficient), where competing methods seem to struggle. Moreover, we also demonstrate that to an extent we can detect change in the parameters, as a video is unrolled, although this requires system excitation. This speaks to the robustness of this approach in practical field deployment. Importantly, the proposed approach was able to generalise well to images captured from a real camera, despite only being trained on simulated data. This highlights the potential value of sim2real techniques for interpreting physical parameters in various applications, and its potential to enable reasoning about physical properties from relatively low fidelity sensor information that is bootstrapped by being grounded in learning from simulation.

Impact

This work deals with the question of robot manipulation in highly dynamic uncertain environments, such as intercepting an unknown bouncing ball using a low quality video stream as observations. This has implications in extending robotics tasks in real-world settings where accurate sensing and well-defined environments may not be available.

Future Work

We are investigating the concept of using flexibly parameterized dynamics simulators directly as models in model-based planning, including the domain of "intuitive physics" within the context of performing useful robotics tasks (e.g. gas-localization, manipulation of soft objects). We explore how we can calibrate real-world scenes with sophisticated physics simulators in order to perform fast inference and motion planning.

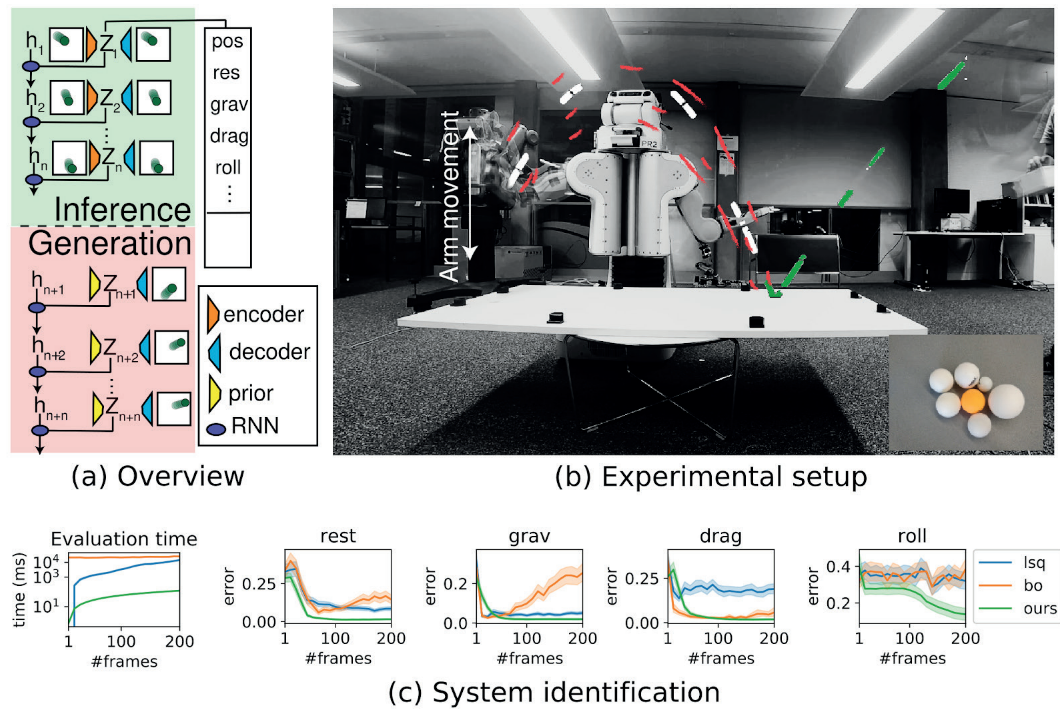


Figure 1:

Overview, experimental setup and results.

(a) Our method is based on the VRNN model with an additional loss to term to encode dynamical properties

(b) We demonstrate the efficacy of our model by conducting experiments with a PR2 robot using its arm to intercept a bouncing ball mid-air, with different types of balls, each starting from a variety of different initial positions.

(c) Performance of different system identification methods with variable number of observed frames in terms of speed of computation and overall error of the predicted parameters on synthetic videos

Research Area: Multi-Modal Interaction

Pilot of the Future: Effectiveness of Sensory Modalities in a Multi-Modal Interface for Varying Task Complexity

Supervisor: Dr Zhibin Li
PhD candidate: Eleftherios Triantafyllidis

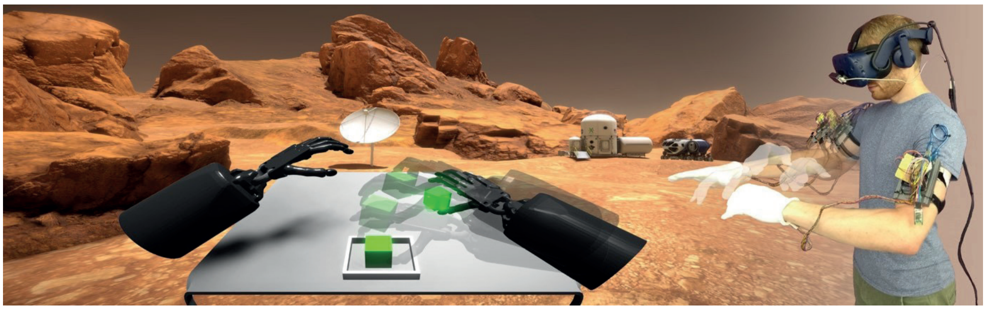


Figure 1: Pilot manipulating via optical hand tracking, objects through a first-person view with virtual reality, auditory as well as haptic feedback.

Objective

Research in multi-modal interfaces aims to provide solutions to embodiment and increase overall immersion. However, an extensive comparison of an audiovisuohaptic multi-modal interface for manipulating tasks of varying complexity is yet missing. Hence, this paper explores this very idea, a thorough investigation of the effectiveness of all combinations of an audiovisuohaptic multi-modal interface and its 8 modalities, reflected upon object manipulation with varying task complexity, in a pick-and-place scenario. We have evaluated our system by conducting a study (N=25), incorporating both subjective measurements, assessing cognitive workload and system usability, as well as objective measurements, by incorporating time and spatial accuracy-based metrics.

Approach

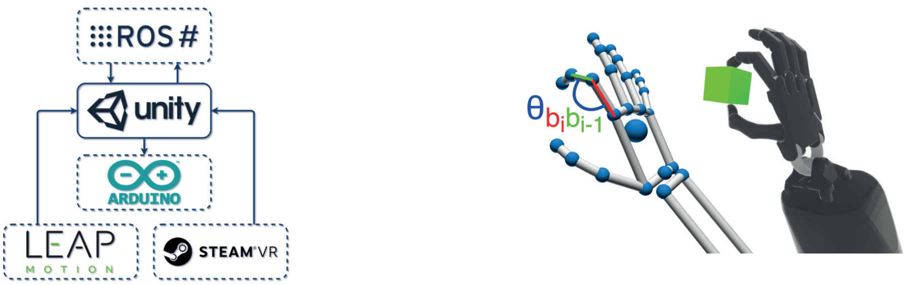


Figure 2: The final simulation environment setup illustrating the primary simulation engine Unity3D accommodating all the necessary software plugins (left) and the re-targeting approach we implemented (right) through direct angle extraction.

To accommodate hand manipulation, we integrated all the necessary physics for a robust object manipulation as well as somatosensory feedback with our haptic capable glove, through numerous plugins into the main simulation environment, the Unity3D engine as shown in Figure 2. As illustrated in Figure 2, by simply calculating the angle between two vectors, we extracted the angle and then re-targeted it directly to the Shadow Dexterous Hand via a simple PD controller.

Finally, we designed the multi-modal interface by first incorporating a generic display monitor and a commercial virtual reality head-mounted display (VRHMD) to serve as monocular and stereoscopic visual feedback respectively. For auditory stimulation, we used a generic audio headset by stimulating both direct sounds from the environment, such as object acquisition, but also warnings such as remaining time for tasks and imminent collisions with the environment. lastly, we implemented haptics by developing our own low-cost vibrotactile capable data gloves.

Results

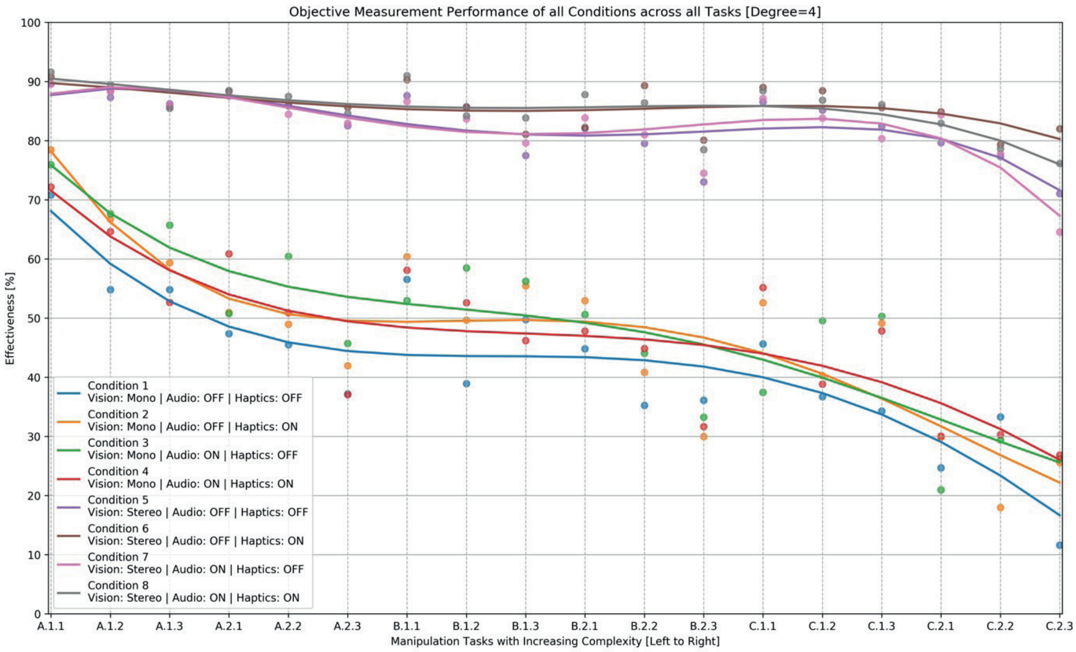


Figure 3: Results, merged in one final polynomial regression figure. The horizontal axis represents the tasks going from lower complexity to higher (left to right). The vertical axis represents the effectiveness of each condition.

Our results show even under increasing gains of task complexity, virtual reality accounted for overall higher performance approximately 40%, across all measurements thus in line with existing literature indicating the dominance of visual stimulation compared to other stimuli ($p<0.001$). Furthermore, results also indicate that somatosensory feedback although not to the scale of stereoscopic feedback, additionally increased overall performance both subjectively and objectively, 10%, particularly in higher task complexity ($p<0.05$). Auditory feedback did not account to a significant observable difference in performance, but did contribute to an increase in spatial accuracy, approximately 5% ($p<0.05$).

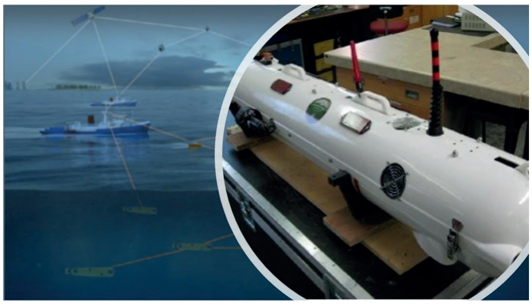
Future Work

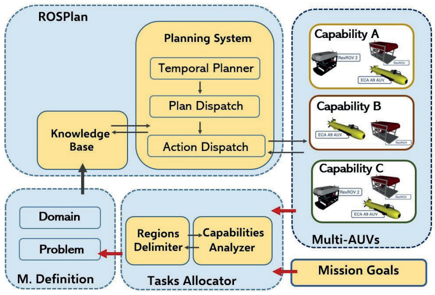
Latency is still very prominent in both remote-piloting applications and in virtual environments concerned with wireless technologies, as such techniques to compensate for high latency interaction, are still very important to be thoroughly investigated.

Research Area: Marine Robotics

Task Allocation Strategy for Multi-Vehicle Systems in the Underwater Domain

Supervisors: Dr Ron Petrick, Professor Yvan Petillot
PhD candidate: Yaniel Carreno





Objective

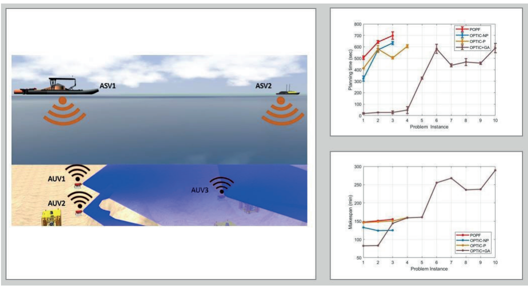
One of the key drivers of current research for marine robotics is the introduction of Autonomous Underwater Vehicle (AUV) into more challenging missions, with much greater complexity and longer execution times using multiple platforms. The difficulty with such an approach is that it must also be supported by robust planning, coordination, and execution tools in order to increase its optimal performance. Planning is particularly promising for maritime robotics since it offers techniques for managing typical problems that arise in the underwater domain, such as limited power and navigational uncertainty. Current temporal AI planners deal with multi-agent planning problems by producing viable plans in complex environments which consider the real tasks requirements and robot capabilities. However, these approaches deal with the high-dimensionality of the state-space inefficiently, leading to multi-robot plans with poor plan quality. We tackle this problem by proposing a novel task allocation strategy called Goal Allocation (GA) which enables the computation of less complex and more efficient plans using temporal planners.

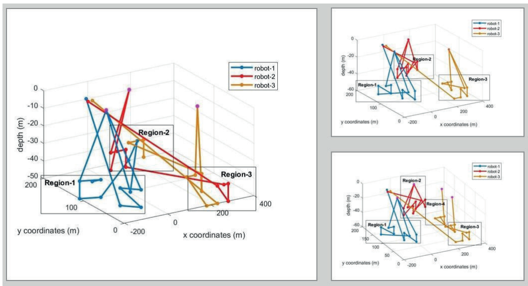
Approach

We attain our goal of allocating the mission's tasks based on robot capabilities and goals spatial distribution avoiding the planner the need to compute a large number of possible assignment costs. We address the multi-agent problem using temporal AI planner. Planning tasks specified in PDDL, the standard Planning Domain Definition Language, are separated into the problem and domain files. Our temporal planning problem is addressed using PDDL2.1. GA algorithm distributes the goals considering the number of robots by generating set of constraints which are added to the problem file used for the planner to generate the plan. The combination of the GA and the temporal planner (TP) gives as a result a plan to be executed by the fleet. We integrate the GA+TP approach and the robotics systems in the mission using ROSPlan framework which dispatches the plan's actions concurrently.

Results

We evaluated our approach performance comparing the results with the outcomes of well-established benchmark planners: POPF, OPTIC-NP (OPTIC-Non Preferences) and OPTIC-P (OPTIC-Preferences). The set of test problems considers 10 problem instances of increasing difficulty. We evaluated the plan quality using makespan, planning time and goal distribution metrics for different robot sets. The figure below shows the Gazebo environment with multiple AUVs and Autonomous Surface Vehicles (ASVs) executing a plan. The makespan and planning time performance are considerably improved if GA algorithm allocates the goals prior to the AI planner generates the plan. The results demonstrate GA+TP is able to distribute the robots in different regions which reduces the possibility of robot collisions, the total distance travelled, and the energy consumed.





Impact

Problems such as long-term seabed inspection, systematic maintenance of offshore underwater structures, and underwater vehicle detection for defence applications require a level of autonomy that AI planners provide. The tasks allocation methods improve the performance of planning solutions and it is crucial to reduce the consumption of resources during the mission.

Future Work

We are investigating a number of exciting directions such as analysing the reallocation of particular tasks among the fleet considering AUV failures and evaluating the performance of the approach in real systems considering real underwater constraints (eg., sea currents). In addition, we are interested in finding a metric to evaluate the plan deviation.

Publications

Carreno, Y.; Petillot, Y.; and Petrick, R. P. 2019. Multi-vehicle temporal planning for underwater applications. In ICAPS Workshop on Planning and Robotics (PlanRob).

Carreno, Y., Petrick, R.P. and Petillot, Y., 2019, July. Towards Long-Term Autonomy Based on Temporal Planning. In Annual Conference Towards Autonomous Robotic Systems (pp. 143-154). Springer, Cham.

Carreno, Y., Petrick, R.P. and Petillot, Y., 2019, June. Multi-Agent Strategy for Marine Applications via Temporal Planning. In 2019 IEEE Second International Conference on Artificial Intelligence and Knowledge Engineering (AIKE) (pp. 243-250). IEEE.

Research Area: Sensor Fusion

A Wide Area Autonomous Telescope for Space Situational Awareness

Supervisors: Dr Daniel Clark, Dr Yoann Altmann, Professor Yvan Petillot
PhD candidate: Mark Campbell

Objective

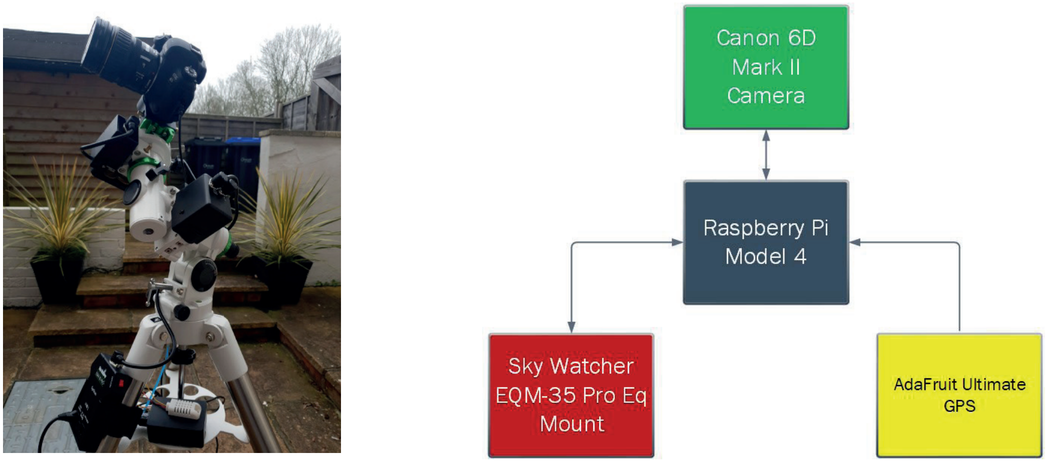
The usage of low-cost ground-based Complementary Metal Oxide Semiconductor (CMOS) optical sensors to track objects in Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO) has dramatically increased in popularity in the past decade, leading to a chance of integrating these sensors into the formal Space Situational Awareness (SSA) environment. These Consumer Of-The-Shelf (COTS) cameras and optics are inexpensive solutions and provide a relatively wide Field of View (FoV); numerous systems and techniques exist such as in [1, 2]. These types of systems are limited by multiple factors: portability, processing power, power consumption, ease of set-up and possibility of reconfiguration. Another feature of these systems is that they all focus on the single target scenario, wherein a single object of interest, a target or specifically a satellite, moves across the sensor's FoV. However, if a wide FoV is desired, the probability of the presence of multiple targets increases dramatically. These systems, based upon the work above, cannot handle detecting and tracking multiple targets simultaneously inside a sensor's FoV.

What is proposed here is an autonomous low-cost, portable and reconfigurable sensor that detects and tracks objects, in spherical co-ordinates i.e. right ascension and declination, that pass through its FoV in potentially close to real time. Such a sensor could potentially be extended to a network of identical sensors or incorporated into an existing network. This system is called the Autonomous Wide Area Tracking Telescope (AWATT).

Approach

The AWATT also aims to exploit low power and cost processing options such as the Raspberry Pi for control and data processing. The AWATT has the following key features:

- Autonomous Detection & Tracking: Can detect and track multiple in frame objects simultaneously using the Linear Complexity Cumulant (LCC) [3] filter.
- Autonomous Control: Using a GoTo mount it can slew and track any position in its observation space.
- Mission Planning: Can either operate in; "hunting" mode, where it opportunistically searches for targets that passes through its FoV or a "targeted" mode where the Two-Line Element (TLE) of a satellite is input and the system attempts to observe it.
- High Portability & Reconfiguration: Low weight, less than 10 Kg, and unfixed components allow for an easy changing of observation position.
- Low Cost: Full prototype system costs less than £3,000, significantly less than competing systems [1,2].
- COTS Equipment: The system only uses commonly used and widely available photography equipment.
- Open Source: The software used in this system will be made available on an open source platform.



(a) (b)

Figure 1: (a) The AWATT system. (b) The hardware used in the system

Future Work

The system will be tested in various real-world scenarios to assess its viability. A possible scenario might consist of an autonomous data collection and processing experiment centered around a well-known and verified target such as the International Space Station (ISS) or CryoSat-2. The output of this experiment should show that the system can accurately and autonomously, detect and track multiple orbiting objects simultaneously and output a set of tracks containing the objects' position in right ascension and declination. It should also be able to do this in close to real-time. Investigation into the effect of different focusing optics will also take place.

After the system can operate autonomously, a next step is to integrate existing Initial Orbit Determination (IOD) methods so that the system can provide an estimate of an object's orbit. Work previously performed in the PhD program for joint tracking and parameter estimation could also be implemented.

Impact

This system is designed as a showcase of the multi-target tracking, sensor estimation and fusion algorithms being developed through the course of the PhD program. However, if it is shown that this system is viable, it could be of great use in the UK's burgeoning need for an increase in SSA capability. The SSA team at DSTL has expressed interest for this reason. This system is potentially extendable to a wide network and could also be used by amateur astronomers and photographers to provide accurate and reliable measurements of Resident Space Objects (RSOs).

References

[1] Jang-Hyun Park et al. "OWL-NET: A Global Network of Robotic Telescopes for Satellite Observation". In: Advances in Space Research 62 (Apr.2018).

[2] P. Bland et al. "FireOPAL: Toward a Low-Cost, Global, Coordinated Network of Optical Sensors for SSA". In: The Advanced Maui Optical and Space Surveillance Technologies Conference. Sept. 2018, p. 14.

[3] D. E. Clark and F. De Melo. "A Linear-Complexity Second-Order Multi-Object Filter via Factorial Cumulants". In: 2018 21st International Conference on Information Fusion (FUSION). 2018. doi: 10.23919/ICIF. 2018.8455331.

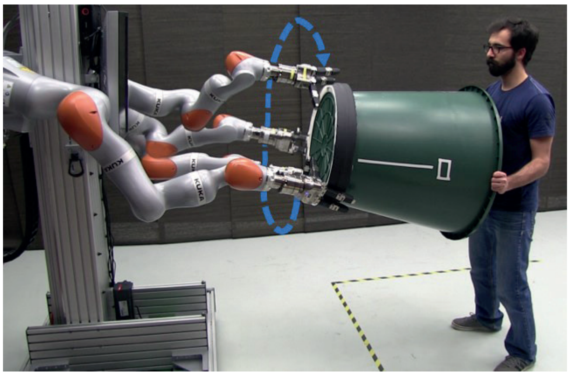
Research Area: Human-Robot Collaboration

Partner Adaptive Dyadic collaborative Manipulation through Informed Hybrid Bilevel Optimization

Supervisors: Professor Sethu Vijayakumar, Dr Michael Gienger
PhD candidates: Theodoros Stouraitis, Iordanis Chatzinikolaidis

Objective

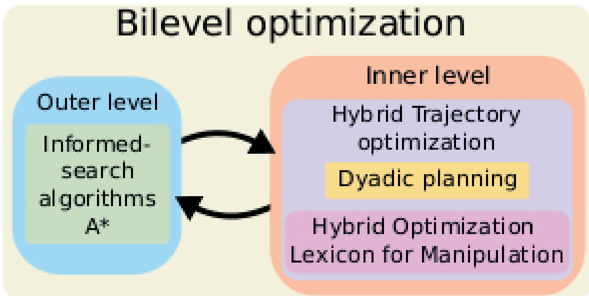
Nowadays, typically robots are found in industrial setups to be either separated from the humans or to perform tangential task to them. Once a human shares the same workspace with a robot, the unpredictability and the variability of humans' actions as well as the limited repertoire of robot actions, generate scenarios with considerable uncertainty to the extent that, robots fail to successfully collaborate with their human partner. In this project, we venture to develop the required theory to overcome the previous mentioned limitations and demonstrate scenarios, in which the robot co-exists with a human partner and both act collaboratively without having predefined plans or separate goals. Specifically, we plan to validate the developed theory on collaborative human-robot manipulation scenarios, where a robot agent collaborates with a human to co-manipulate a large object. Towards achieving this goal, this particular piece of work is focused on how a robot policy can be partner-aware and flexible towards complying with the requirements of DcM scenarios.



Current state of the art approaches have demonstrated robot policies that consider the partner's actions, however the achieved flexibility is limited as the graps-holds utilized by the robot are always fixed. On the contrary human dyads exploit the redundancy in the contact space, in order to realize the optimal solution. The proposed method enables robots to generate on-the-fly hybrid motion plans that exploit simultaneously both the contact and the force space towards finding the optimal joint solution, by taking into account the policy of the human partner.

Approach

First, we refer to Dyadic co-Manipulation (DcM) as a set of two individuals jointly manipulating an object, as shown in the figure above. The two individuals partner together to form a distributed system, towards augmenting their manipulation abilities. In the proposed method a continuous optimization problem (inner level) is embedded in a discrete (outer level) one, as shown in the figure on the right.



We exploit the efficiency of informed search methods to compute online hybrid motions with the fidelity of trajectory optimization. The required a-priori knowledge is a rough known model of the partner's policy and a model of the object. Our method computes optimal solutions on-the-fly for the i) trajectory of the object, ii) robot agent forces, iii) robot agent contact locations, iv) the number of contact changes and iv) respective timings of these actions. A graphical illustration of the interplay between the discrete and continuous optimization, in the content of hybrid motion, is shown in Fig.1. The partner's intentions are represented as task space goals, while the partner's policy is abstracted as task space wrenches to model the effects of joint manipulation. The concept is demonstrated both in simulation as well as with a real world dyad of a human and a robot.

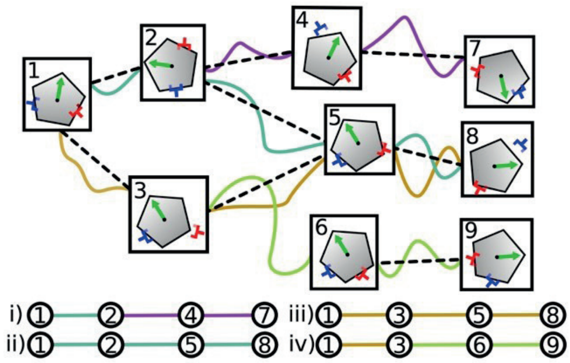


Figure 1: A representative illustration of the four different solution paths i) to iv) obtained with the proposed bilevel optimization method. The dashed lines depict the discrete transition found from the outer (discrete) level of the optimization, while the full lines are the sub-paths obtained from the inner (hybrid) level of the optimization

Results

We performed extensive analysis on the flexibility and computational requirements of the hybrid plans, while one such hybrid plan is shown in Fig.2. The experiment with a 32 DoFs robot demonstrates that the solutions have a large potential to be employed in real co-manipulation scenarios. Regarding the motion of the robot, as the algorithm provides the end-effector poses, IK are utilized to compute the configuration of the robot.

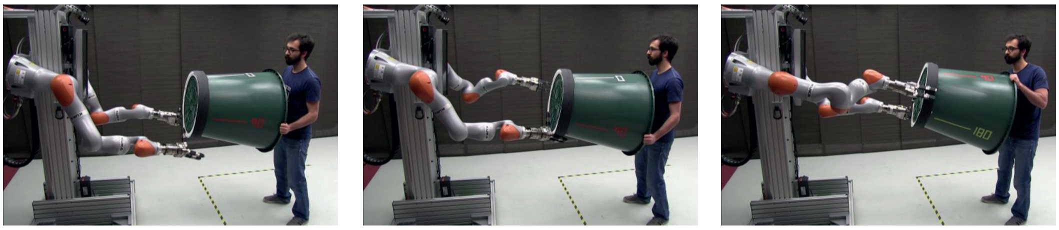


Figure 2: DcM scenario with a human partner and a robot during change of contacts

Future Work

We aim to develop robotic agents capable of manipulating their environment in collaboration with their human partners, such that robots will become equal industrial partners and competent home assistants. Thus, our future work will focus on elaborate models for the human policy, towards realizing robust behaviour in interaction between the robot, the object and the human partner.

Publications

Theodoros Stouraitis, Iordanis Chatzinikolaidis, Michael Gienger, Sethu Vijayakumar. *Dyadic Collaborative Manipulation through Hybrid Trajectory Optimization,* Conference on Robot Learning (CoRL), 2018. (Best System Paper Award Finalist - Oral presentation 8% acceptance rate)

Research Area: Human Robot Interaction

Disentangled Relational Representations for Explaining and Learning from Demonstration

Supervisors: Dr Subramanian Ramamoorthy, Professor Alex Lascarides
PhD candidates: Yordan Hristov, Daniel Angelov

Objectives

Learning from demonstration is an effective method for human users to instruct desired robot behaviour. However, for non-trivial tasks of practical and industrial interest, efficient learning from demonstration depends crucially on inductive bias in the chosen structure for rewards/costs and policies. We address the case where this inductive bias comes from dialogue with the human user. We propose a method in which a learning agent utilizes the information bottleneck layer of a high-capacity variational neural model, with auxiliary loss terms, in order to ground abstract concepts such as spatial relations. The concepts are referred to in natural language instructions and are manifested in the high-dimensional sensory input stream the agent receives from the world. We evaluate the properties of the latent space of the learned model in a photorealistic synthetic environment and particularly focus on examining its usability for downstream tasks. Additionally, through a series of controlled manipulation experiments, we demonstrate that the learned manifold can be used to ground demonstrations as symbolic plans, which can then be executed on a PR2 robot.

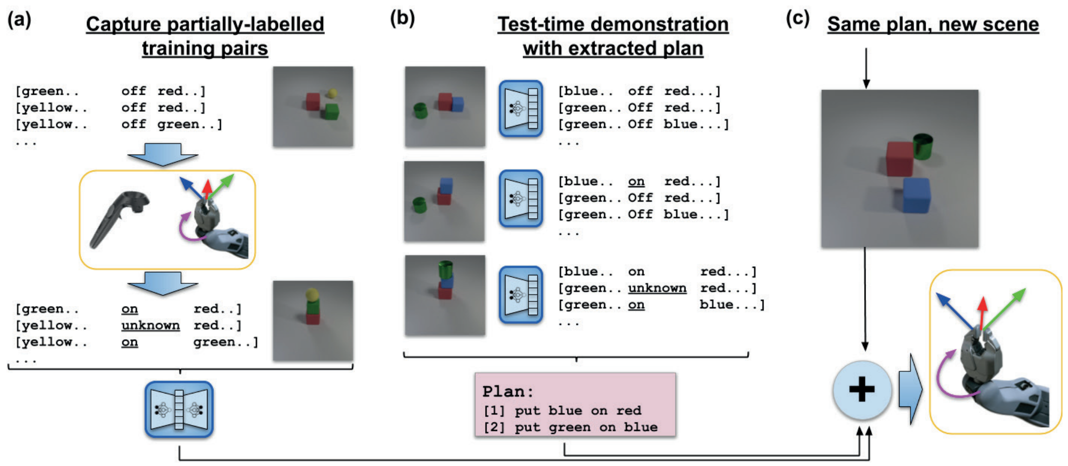


Figure 1: Overall setup: (a) during training, the agent receives observations from the environment and weak annotation from the human expert as to how different objects relate to each other, at each time step. (b) At test time, the agent uses the learned representations in order to explain how the objects in the environment relate to each other, through time, with the explanation being structured in the form of a plan; (c) each instruction from the plan can then be mapped to end-effector actions.

Approach and Results

We present a method for learning disentangled representations in which inter-object relationships, manifested in a high-dimensional sensory input, can be grounded in a learned low-dimensional latent manifold—see Figure 2. We explicitly optimize for the latent manifold to align with human 'common sense' notions, e.g. left and right are mutually exclusive and independent from front and behind which are also mutually exclusive. Evaluation of the learned representations is performed in an 'Explain-n-Repeat' setup—see Figure 1—in which discrete symbolic specifications, grounded in the learned manifolds, can be derived from the latent projections of user demonstrations. The demonstrations are third person observations of object manipulation in a table-top environment.

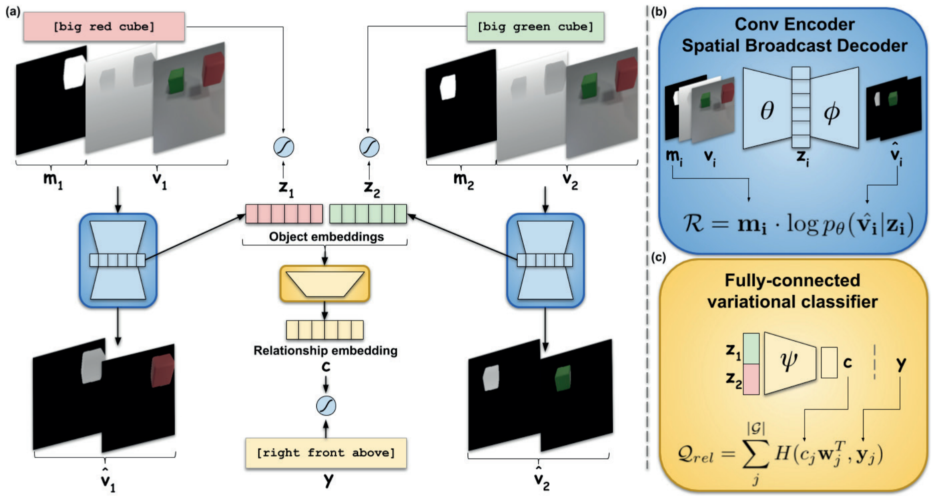


Figure 2: Overall architecture - two object-centric embeddings are produced for each masked RGBD input. From their concatenation a relationship embedding is produced. Parts of all embeddings are fed through a set of linear classifiers in order to predict a set of discrete labels - one group of labels per latent axis. Additionally the object-centric embeddings are used to reconstruct the original input

We show that while interpretable to the human, due to the disentanglement we explicitly optimize for, the learned latent space is also useful to tasks downstream. In particular, using photorealistic synthetic demonstrations we show how such a feature space can be used by an agent to infer both what is moved after what and how each object is individually manipulated. An explanation for the observed movements is derived, using the symbols the agent has been taught how to ground a priori. We also show how such discrete symbolic representations can be used as a building block for primitive action policies in the context of a robotic agent performing a table-top manipulation task.

Impact

This work is supported in part by a Turing Institute project on Safe AI for surgical assistance. Our work is a step in the direction of enabling the surgical staff to be able to instruct a robot with action commands in a seamless manner, while also having that system be verifiable in terms of its behavioural properties.

Future Work

Effective human-robot collaboration requires shared task representations that are both interpretable and suitable for task completion. The described setup represent steps towards a programme of work, at the centre of which is interpretable physical symbol grounding. We are currently working on methods that would allow for faster task-oriented motor control policy learning performed by a robot in the presence of an expert.

Publications

[1] Y. Hristov, D.Angelov, M. Burke, A. Lascarides, S. Ramamoorthy, Disentangled Relational Representations for Explaining and Learning from Demonstration, arXiv preprint arXiv:1907.13627, 2019

Industrial studentships

Statistical Methods for AUV Underwater Pipeline Tracking in Multi Sensor Data

Kawasaki Heavy Industries, Kobe, Japan

Pipeline tracking is a challenging task for Autonomous Underwater Vehicles because sections of the pipe may be deliberately buried and not visible from the surface. This project investigates multi-sensor solutions to tracking pipelines in and out of burial from an AUV flying low over the pipe using multi-sensor data, to be selected from sub bottom sonar, wideband biosonar, magnetometer, laser and video. The PhD work focuses on statistical methods for tracking, starting with the Probability Hypothesis Density filter.

Cooperative Control of Drilling Equipment

Schlumberger, UK

As automation of drilling processes is developed, operation will be split between completely automated tasks and tasks that are carried out by humans. The project looks at how teams comprising human and robotic actors can collaborate to achieve complex and uncertain tasks in drilling operations.

Interactive robotic inspection strategies using unstructured data

Renishaw, UK

Document based 2D technical drawings rather than a digital 3D model are still the main format in a production-inspection workflow. This research is focused on using unstructured data such as the symbolic representations of geometric dimensioning and tolerance (GD&T) as input to conduct a teach-execute regime for coordinate measuring robots.

Shared Autonomy for Kinesthetic Tools

Costain, UK

Many repetitive industrial tasks require significant cognitive load which results in operator fatigue and in turn can become dangerous. The development of robotic sensing technology and compliant feedback technology will allow semi-autonomous robotics systems to improve this type of work flow. This project aims to explore methods in which a robotic system with shared autonomy can contribute to the operation of a Kinesthetic tool (such as a piece of machinery) and in doing so reduce the cognitive load and fatigue of the human operator.

Learning to grasp movable objects based on tactile information

Honda Research Institute Europe

Intelligent systems will shape our future in a variety of forms, ranging from accident-free mobility to cognitive robotics and from smart process management to the efficient use of resources. Intelligence is necessary to handle complexity in products and in processes. The goal of this industrially sponsored project is to research concepts and methods for tactile-based exploring and grasping of movable objects.

Bridge Inspection - Inspection of brickwork and masonry assets
RSSB, UK
This project aims to inspect the brickwork and masonry assets of railway bridges, particularly the intrados of arches where access is limited. The project will use drones to collect images autonomously under the arches and then analyse the images to automatically detect the defects in the structure.

Intention-aware Motion Planning
Thales, UK
The goal of this industrially sponsored project is to research and extend previous techniques to give a new approach to categorising motion and inferring possible future system states to support robust maritime autonomy decision making processes.

Long term autonomy for multi agent systems in the maritime domain
BAE Systems
The main aim of this project is to develop algorithms that can devise, execute and monitor plans suitable for long-term missions of marine 'systems of systems' where overall goals are well defined but their effective implementation is dependent on external parameters than cannot be pre-determined.

Intention Aware Human-Robot Collaborative Manipulation of Large Objects
Honda Research Institute Europe
Until the past few years, robots were typically temporally or spatially separated from human co-workers to ensure humans' safety. In the case of today's cobots that's not the case anymore. However the unpredictability and the variability of humans' actions generate scenarios with frequent plan alternations and considerable uncertainty, to the extent that robots fail to successfully complete the collaborative tasks in hand. This project aims at developing the required theory to overcome these limitations and demonstrate collaborative human-robot manipulation scenarios. In Dyadic co-Manipulation (DcM) scenarios, a robot collaborates with a human as naturally as a dyad of humans would do. In the future, the direct societal impact of this research will be found in daily scenarios where robots will assist humans to manipulate objects of interest.

Towards Full Autonomy: Deep Learning Enhanced Scene Understanding for Underwater Robots
SeeByte Limited
This project will investigate state-of-the-art driven machine learning techniques, e.g. Convolutional and Recurrent Neural Networks, as well as Deep Reinforcement Learning techniques, extending these novel approaches to be applicable to the underwater robotics domain.

Mobile inspection units on the train
RSSB, UK
This project aims to develop robotized inspection units that can navigate and manipulate in the confined work spaces typical of in-between and under the seats of a train cab. The typical application for an on-train mobile robot platform is inspection of the compartments for cleaning and hazard identification purposes. The platform is also intended to have manipulation capability to perform some cleaning tasks.

Industrial Partners

Engaging with the Centre

Robots will revolutionise the world's economy and society over the next twenty years, working for us, beside us and interacting with us.
The UK Engineering and Physical Sciences Research Council (EPSRC) has recently invested nearly £500m in new Centres for Doctoral Training (CDTs) to develop industrially relevant, cutting-edge technologies and the research leaders of the future.
The Edinburgh Centre for Robotics, a £120M joint venture between Heriot-Watt University and the University of Edinburgh, has been running an EPSRC CDT in Robotics and Autonomous Systems since 2014, training around 70 highly-skilled graduates. As a result of a successful follow-on bid, we are pleased to announce an additional eight years of funding which will allow us to train a further five cohorts of between 10-15 innovation-ready PhD students annually.
In order to maximise the number of students who can benefit from this programme, we invite proposals for new research projects from companies with a research activity in the UK.

The theme of the CDT RAS 2.0 is **Safe Interaction**, which includes the following topics:

Physical Interactions:
Control, actuation, compliance, sensing, mapping, planning, embodiments, swarming

People Interactions:
Human-robot interaction, affective robotics, smart spaces, teaming, collaborative decision-making, cobots, multimodal interfaces

Self-Interactions:
Condition monitoring, prognosis, explainable AI, certification, verification, safety, security

Interaction Enablers:
Vision, embedded and parallel computing, novel fabrication methods, machine learning algorithms and other AI techniques including NLP

How to engage with the Centre

A company can choose to support a relevant PhD research project in a university laboratory, in return gaining early access to results, the potential to exclusively license foreground IP and the right to host the student at their site for 3 months of the project. Companies generally provide financial support for stipend, UK/EU fees and project costs.

Entry to the programme is in September, with students completing two semesters of taught courses whilst starting to explore their PhD research direction.

Project proposals from companies are accepted throughout the year but are particularly encouraged by the end of March to allow recruitment to the programme in the new academic year.

In addition to funding a studentship, companies can also provide support by:
- Providing access to equipment/software at their premises
- Co-supervision of students and projects
- Student placements and internships
- Contribution to MSc taught programmes
- Support for student robot competitions

If you are interested in engaging with the Centre, please contact:
Professor Helen Hastie h.hastie@hw.ac.uk
Dr Michael Mistry michael.mistry@ed.ac.uk

Highlights 2018-19

TRAINING
EDINBURGH CENTRE FOR ROBOTICS

Centre for Doctoral Training receives funding for Phase II

Edinburgh Centre for Robotics, a joint venture between Heriot-Watt and Edinburgh universities, has secured £7M to expand its successful EPSRC Centre for Doctoral Training in Robotics and Autonomous Systems (CDT-RAS). This is supported by significant funding pledged by our industry partners.

The funding from EPSRC and industry will train 90 PhD students, in five cohorts, over the next eight years. Research will focus on safety and safe interaction between robots, people and their environments.

The first cohort of 14 students will join the CDT in September 2019, with phase II being led by new directors Professor Helen Hastie (HWU) and Dr Michael Mistry (UoE).

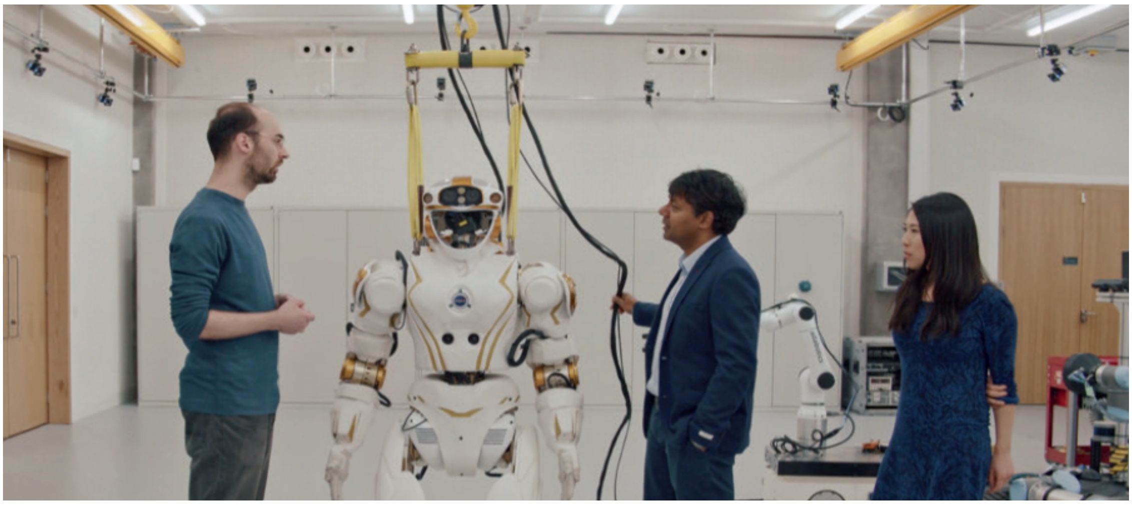
"We're looking forward to training the next generation of innovation-ready scientists and engineers in Robotics and Autonomous Systems focusing on the aspect of safe interaction, which will be key to adoption of this technology in the near future."
Professor Helen Hastie, Director (HWU) RAS CDT Phase II

"Winning a second CDT-RAS recognises our success to date in science and innovation, and expands the foundational science and training platform that underpins our planned expansions into living labs, accelerators and incubators in the National ROBOTARIUM. We have become a core component in implementing the UK's RAS2020 Strategy, whose success is helping to shape the nascent UK Robotics Growth Partnership. We are putting UK in an internationally leading position creating and commercialising core science to capture the value from the disruptive productivity gains RAS can offer across a range of sectors."
Professor David Lane, Director of the Edinburgh Centre of Robotics

"As we welcome in our first cohort of bright students, we are excited to get the next phase of the CDT underway. Our students will be working in a world-class research environment and will have plenty of opportunity to collaborate with our international academic and industrial partners. We look forward to our students' achievements in the coming years."
Dr Michael Mistry, Director (UoE) RAS Phase II

Bayes Centre opens at University of Edinburgh

The £45 million Bayes Centre at the University of Edinburgh was officially opened by Her Royal Highness, The Princess Royal in October. The building, spread over five floors, will be home for around 600 researchers, students and entrepreneurs. The design includes open spaces and a central atrium to encourage collaboration among occupants.



Edinburgh Centre for Robotics has just completed its move to the brand new bespoke facilities and Professor Sethu Vijayakumar is delighted with the new ROBOTARIUM East space:

"We want to push the robots to their limits and this is a custom built space in which to do exactly that. What's fantastic about the Bayes is that it brings together talent, be it parallel computing from EPCC (formerly the Edinburgh Parallel Computing Centre) or mathematical expertise from ICMS, (International Centre for Mathematical Sciences) or from across the Turing's network, which is great for the cross-pollination of ideas."

Scottish Minister for Trade, Investment and Innovation, Ivan McKee visits Centre

We were delighted to host the Minister and show him the work being undertaken in robotics at Heriot-Watt University. During the visit Mr McKee was given a tour of the Ocean Systems Lab where Professor Yvan Petillot gave a demonstration of the tank facilities with sub-surface robot and sensor networks.

We were also able to show Mr McKee around the Human-Robot Interaction Lab where he was shown a 'chatbot' helping in an emergency situation. Dr Adam Stokes and his ORCA research team from the University of Edinburgh provided a demonstration of the 'Husky' mobile platform and Limpet sensors.

Highlights 2018-19(cont)

Green Light for National Robotarium

The creation of the UK's first National Robotarium reached a significant milestone on 17th December after its business case was approved by the Edinburgh and South East of Scotland City Region Deal Joint Committee.

The multimillion pound hub, to be built at Heriot-Watt University in collaboration with the University of Edinburgh, will be the UK's leading innovation hub for robotics and autonomous systems, delivering leading-edge research and support for business creation and growth, as well as data skills.

The new Robotarium will build on Heriot-Watt's ground-breaking robotics research which is already contributing towards the drive to revolutionise manufacturing, healthcare, offshore energy, construction and marine science.

Set to be opened in 2021, the new hub is an integral part of the Data Driven Innovation (DDI) theme of the Edinburgh and South East Scotland City Region Deal, and will aim to establish the region as the data capital of Europe – attracting investment, fuelling entrepreneurship and delivering inclusive growth.

As part of the Deal, the UK and Scottish Governments are set to invest £300m each over the next 15 years with other partners committing to an additional £700m. The £1.3bn investment is anticipated to generate over £5bn worth of Gross Value Added (GVA) over the Deal's lifespan.

Professor Richard A Williams, Principal and Vice-Chancellor, Heriot-Watt University said:
"I am delighted to have confirmation of our ambitious plan to develop the UK's first National Robotarium. Its work will be a critical part of establishing Edinburgh as a hub for digital transformation, and assuring its global reputation for innovation. We are looking forward to connecting our universities, business and community partners so Scotland will be at the forefront of developing the future digital economy to serve society's needs."

Find out more about the National Robotarium at https://www.youtube.com/watch?v=dchENR5mh5k

NATIONAL ROBOTARIUM

Heriot-Watt Team Alana reach finals of the 2018 Alexa Challenge

Students from the CDT have played a role in helping Heriot-Watt University reaffirm its position as a world leader in robotics and artificial intelligence after their team reached the final of the Amazon Alexa Prize for the second year running.

The Amazon Alexa Prize is dedicated to the advancement of conversational artificial intelligence, and challenges teams to develop software capable of understanding and responding to humans in a socially intelligent manner over many different topics of conversation such as news, music, movies, and celebrities. It is named after the Alexa voice command system that powers the Amazon Echo smart home device.

Over the last 18 months, thousands of AmazonAlexa customers in the USA have put the software through the ultimate test by conversing with the finalists' socialbots on a host of popular topics. They then gave their feedback based on whether the conversation flowed naturally and if the technology was up to the task.

Heriot-Watt was successful in reaching the final three teams, the only UK university to do so, having overcome stiff international competition from 200 entrants. Team Alana, comprising of six PhD students and four faculty advisors, successfully developed a highly sophisticated artificial intelligence software capable of understanding and responding to human conversation. The University's Team Alana narrowly missed out on the top prize after finishing in third place behind the Czech Technical University and the overall winners, University of California Davis, at a ceremony held in Las Vegas on Monday 26th November.

Alana Team Leader, Amanda Cercas Curry, a Computing Science PhD student, was in Las Vegas for the ceremony and said:

"I'm very proud of the high-calibre of work carried out by this team and we can all feel extremely proud of reaching the final of this global competition for the second year in a row. Being part of this team and the competition has been a great experience and one I will never forget. Developing production-ready AI systems is never easy but we leave here with valuable insights that we can use in our future careers."

Professor Richard A. Williams, Principal and Vice-Chancellor of Heriot-Watt University, praised the team's achievement saying:

"I congratulate everyone involved in Team Alana in reaching the final of the Amazon Alexa Prize for the second time in as many years. Our involvement in such a prestigious competition only serves to demonstrate the tremendous talent we have and helps promote the name of Heriot-Watt around the world, showcasing us as global leaders in robotics and artificial intelligence."

amazon alexa

Highlights 2018-19 (cont)

Heriot-Watt takes centre stage on Tomorrow's World Live!
Centre students and academics have appeared in a live, one-off special of BBC's science and technology programme Tomorrow's World on BBC 4.

Professor Oliver Lemon from the School of Mathematical and Computer Sciences staged the BBC's first live chat with Alana, one of the world's most sophisticated conversational AI systems.

The programme also featured NAO robots which are used in Heriot-Watt's public outreach activity to help engage young people in STEM, and MiRos, a transgenerational companion robot pet.

Commenting on the Tomorrow's World appearance, Professor Lemon said:
"Appearing on Tomorrow's World Live was a wonderful opportunity for the University, and our school in particular, to showcase our research in conversational AI. Our system is among the most advanced in the world but creating coherent dialogue between a human and a machine, handling all the nuances and subtleties of language, still has a long way to go. We are building Alana's understanding of language all the time.
In the future, systems like Alana will act as our personal assistants and companions, helping us in our everyday tasks and supporting communication with robots. Conversational AI systems can also be used in care applications, for example prompting people to take their medication, and even helping to reduce social isolation.
We hope that our appearance on the programme will help inspire others, especially young people, to consider a career in computer science, AI and STEM subjects in general."

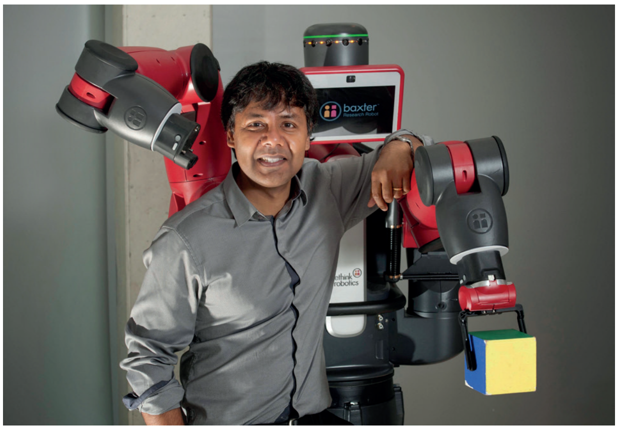
The Alan Turing Institute

Sethu Vijayakumar joins The Alan Turing Institute as Programme Co-Director for AI

Sethu Vijayakumar has been recently announced as Programme Co-Director for Artificial Intelligence (AI) at the Alan Turing Institute.

The Alan Turing Institute is the national institute for data science and artificial intelligence named in honour of Alan Turing whose pioneering work in theoretical and applied mathematics, engineering and computing are considered to be the key disciplines comprising the fields of data science and artificial intelligence.

Five founding universities – Cambridge, Edinburgh, Oxford, UCL and Warwick – and the UK Engineering and Physical Sciences Research Council created The Alan Turing Institute in 2015. Eight new universities – Leeds, Manchester, Newcastle, Queen Mary University of London, Birmingham, Exeter, Bristol, and Southampton – joined the Institute in 2018.



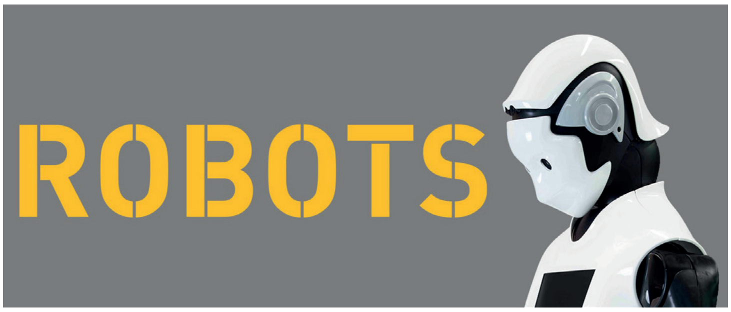
In an interview with the Alan Turing Institute, Sethu commented on the opportunities arising from his appointment **"My ambition is to try to marry my passion for machine learning and statistical methods, in which the UK has world class talent, with solving problems arising from, and in the deployment of, robotic platforms. There are some very interesting theoretical, conceptual, and algorithmic problems that come up in the robotics domain that can be very good challenges for people working in data science to tackle."**

With regard to his vision for how the relationship between the Alan Turing Institute and Bayes Centre will enable the sharing of these challenges, Sethu stated **"We want to create living labs that bring together different stakeholders to test technology in real-world scenarios. We can do this by enabling core developments in data science and scalable algorithms and bringing in end users and companies to develop proof of concept test beds, to help translate world class lab research. With the Turing's network we'll have access to the right kind of talents to push this work forward."**

He is also keen to ensure that the perception of robotics and AI is positive, but also realistic. **"As practitioners we need to be able to tell the public, and law makers and the government, about the tremendous opportunities of technology, but also what its limitations are. We want to 'bust the hype', manage expectations, and allay fears."**

Highlights 2018-19 (cont)

National Museums Scotland

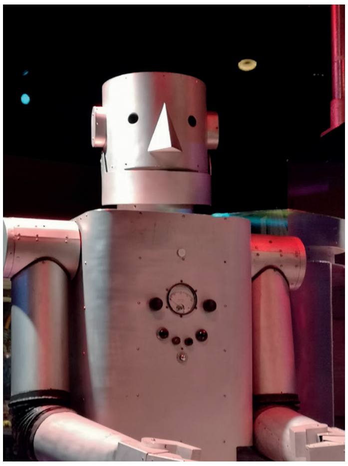


Robots - Discover the 500-year quest to make machines human

The National Museum of Scotland hosted a major exhibition of robots at its Chambers Street galleries from January to May 2019. Featuring more than 100 objects, this was the most significant collection of humanoid robots ever assembled. The exhibition included early clockwork machines and a T-800 endo skeleton which featured in *Terminator Salvation*. Visitors learned about the latest innovations in robotics research and had the opportunity to see some of the latest humanoids in action.

Edinburgh Centre for Robotics created a virtual interactive touchscreen experience of the Valkyrie robot for the exhibition which gave visitors a behind-the scenes insight into the ground-breaking work being carried out at the Centre.

The exhibition was highly successful, attracting over 60,000 visitors, and receiving excellent reviews and significant media coverage.



NASA Scientist gives keynote

The Centre was delighted to welcome Dr Kimberly Hambuchen, Principal Technologist at the Space Technology Mission Directorate at NASA in Houston to a full programme of events in Edinburgh. Dr Hambuchen's itinerary started with a visit to a local school to inspire the pupils with her talk about the NASA robots. This was followed by a keynote to academics and students at the University of Edinburgh when Dr Hambuchen discussed previous, current and future technology developments in robots at NASA, from rovers on Mars, to humanoid spacecraft caretakers, to icy moon explorers. The presentation covered research activities that span multiple NASA centres, and multiple archetypes of robotic systems that can assist in exploration at all stages of space missions. Dr Hambuchen concluded by discussing NASA's future deep space efforts which are focused on cis-lunar activities, and how robots can enable new mission paradigms, including autonomous space habitats and human-robot teaming.

UK Government Minister for Scotland visits the Centre

UK Government Minister Robin Walker was given a tour of Heriot-Watt University's world leading robotics facilities as he discussed progress on the creation of a National ROBOTARIUM.

The proposed facility, which is supported with £21 million from the UK Government, will be a world-class hub, developing and utilising the next generation of robot technology which has the potential to transform lives, industry and our economy.

It will provide a state-of-the-art base from which researchers, engineers, entrepreneurs and educators will deliver the UK's leading international centre for the generation of new smart robotics companies, accelerating Edinburgh and Scotland to be at the forefront of this growing global industry.

Professor David Lane, Director, Edinburgh Centre for Robotics and ORCA Hub, said:
"Our significant robotics research is already contributing towards the drive to revolutionise manufacturing, healthcare, offshore energy, construction, environmental monitoring and defence. The National ROBOTARIUM will place Scotland at the forefront of developing the future digital economy to serve society's needs. We were thrilled to meet with Minister Robin Walker to share our ground-breaking work and discuss the National ROBOTARIUM's progression."

UK Government Minister for Scotland Robin Walker said:
"It was great to hear how the National ROBOTARIUM plans are progressing. Through projects like this, the City Region Deal will help develop Scotland's world-class higher education and research sector, bring new opportunities and boost economic growth across Edinburgh and the South East of Scotland. The UK has a proud record as a world leader in technology and investments such as this one with the UK, Scottish and local government working together with innovative universities. This can build on Scotland's proud record of innovation to ensure that we lead the world in embracing the opportunities of robotics."

Achievements

Student Research Competition Success

Edinburgh Centre for Robotics student Siobhan Duncan (2016 cohort) was awarded first place in the ACM SIGAPP Symposium on Applied Computing Student Research Competition held in Cyprus in April for her work titled "Bringing Stigmergy into the Real World"

Stigmergy is a form of indirect communication that is found throughout the natural world. Simply put, an action carried out by an agent creates a trace in the environment that can then be sensed by the same or another agent. This has the probability to prompt some further action and this feedback loop is a key component in coordinating decentralised swarm systems.

Siobhan's work looks at applying this concept in novel ways, both by taking advantage of modern technologies such as the cloud, as well as conceptually moving away from more traditional pheromone-style "I was here" approaches and towards leaving richer traces of information such as sensor and decision-making data.

The competition, sponsored by Microsoft, invites graduate students to submit original and unpublished work for knowledge exchange and feedback from the research community. Initial submission takes the form of a two-page extended abstract that emphasises the innovation behind the student's work.

Eighteen students, funded by a USD500 travel award from Microsoft, were invited to present a poster at the conference from fifty-seven abstract submissions. During the poster session a panel of five judges asked each student about their work, marking them on oral presentation, poster quality and research methods. This resulted in a shortlist of five students from Scotland, Israel, Pakistan, Iran and Spain who were invited to give a 10-minute presentation on their work to the main conference chairs. The finalists were invited to the conference banquet where the top three prizes were announced with Siobhan winning first prize.

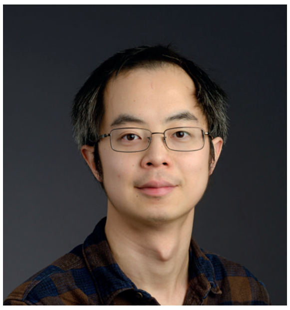
Best paper award nomination

Students and academics from the Centre were nominated for a best paper award at the Conference on Robot Learning 2018 (CoRL18) which took place in Zurich in October 2018. The conference focuses on the intersection of robotics and machine learning and aims to be a selective, top-tier venue for robot learning research, covering a broad range of topics spanning robotics and ML, including both theory and practice.

Their paper "Dyadic collaborative Manipulation through Hybrid Trajectory Optimization", authored by PhD candidates Theodoros Stouraitis and Iordanis Chatzinikolaidis, and Dr Michael Gienger and Professor Sethu Vijayakumar, was one of 75 out of 237 submitted papers accepted (31% acceptance rate) by the conference committee.
In addition to being nominated along with six other papers for best paper awards, the paper was one of nineteen selected (8% acceptance rate) for a full-length oral presentation.

Student wins prestigious RSE scholarship

RAS CDT student Derek Chun has been awarded the John Moyes Lessells Travel Scholarship from the Royal Society of Edinburgh to carry out research in Japan with Prof. Koh Hosoda of Hosoda Lab, Osaka University. This is an amazing achievement as the scholarship is open to all branches of engineering in Scotland and Derek has succeeded in making his application stand out from all others.



Derek's PhD research work within the Edinburgh Centre for Robotics provides him with opportunities to travel to international conferences and workshops that are relevant to his research topic, allowing him to meet the authors of the key papers that are shaping his PhD in soft robotics systems and their potential in physical human-robot interaction applications. Derek met Koh Hosoda at a couple of conferences and the conversations started, resulting in the opportunity to travel to Koh Hosoda's Lab, which specialises in soft pneumatic humanoid robotics.

Derek will be based in Osaka for three months and his time there will enable him to further understand the energy interactions between humanoid robotics and the environment. He will provide an energy-based approach to analyse and develop humanoid systems based on his PhD.

CDT students win Heriot-Watt University Enterprise Funding

CDT students Hugo Sardinha, Ioannis Chalkiadakis and Siobhan Duncan, championed by Dr. Patricia A. Vargas, are recipients of the Enterprise Fund, an initiative from Santander Universities in collaboration with Heriot-Watt University. This initiative consists of pre-seed funding aimed at enabling students, who have a business idea, to develop their initial prototype and boosting their chances of success in future investment rounds.

"The Enterprise Fund is a fantastic opportunity for the three of us to continue developing our business idea in the field of aerial robotics. More so since we are building on the top of Edinburgh Centre for Robotics own Innovation Funding programme. Having this variety of funding avenues available is definitely a game changer when it comes to early stage start-ups, where many times, the first challenge is precisely to find resources for a proof-of-concept prototype. We certainly are confident this will help us deliver a higher quality product"

Hugo Sardinha, 2016 cohort

Achievements (cont)

Student wins national prize for academic excellence

Èric Pairet received the National Prize for Academic Excellence from the Ministry of Science, Innovation and Universities of the Government of Spain. Particularly, he was awarded with the first prize in the branch of engineering and architecture out of 336 pre-selected candidates among all engineering and architecture students in Spanish universities. This prize, which recognises outstanding academic and research trajectories, is the highest honour for a Spanish graduate student.

Before joining the CDT, Èric got his bachelors in Electronics and Automation Engineering at the University of Girona, Spain. Then, he undertook the Erasmus Mundus Master in Computer Vision and Robotics (VIBOT) from the University of Burgundy, France, University of Girona, Catalonia, Spain, and Heriot-Watt University, Scotland, UK. During his studies, Èric was actively working in industry and as a researcher at the Underwater Vision and Robotics Research Centre (CIRS) from the University of Girona.

The award ceremony was celebrated on June 26th 2019 at "Teatro de la Zarzuela" in Madrid, Spain, and was presided over by Pedro Duque, Minister of Science, Innovation and Universities of the Government of Spain.

Best Paper Award in TAROS Conference

Paola Ardón and Èric Pairet attended to the 20th Conference Towards Autonomous Robotic Systems celebrated at Queen Mary University of London from the 3rd to the 5th of July 2019 to present their research to the British robotics academic community and industry.

TAROS is the longest running UK-hosted international conference on Robotics and Autonomous Systems (RAS), which is aimed at the presentation and discussion of the latest results and methods in autonomous robotics research and applications. This year's edition had the keynote speakers Prof Aude Billard, Prof Véronique Perdereau, Dr Francesco Nori and Prof Bruno Sicilliano.

Paola's paper on "Reasoning on Grasp-Action Affordances" was finalist in the best paper award of the overall 2019 TAROS conference. This prize was sponsored by Springer.

Èric's paper on "Learning and Composing Primitive Skills for Dual-arm Manipulation", was awarded with the best paper award of the overall TAROS 2019 conference as voted by the audience. This prize was sponsored by the Advanced Robotics at Queen Mary University.

Student internships

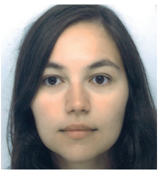
The following CDT students are currently undertaking prestigious internships which give them experience of carrying out research in a large organisation and help them develop skills that will be beneficial when they return to their PhD studies.

Martin Asenov (2016 cohort) has spent 3 months working as a Research Assistant at Amazon PrimeAir in Graz in Austria.

Marian Andrecki (2015 cohort) is interning at Proportunity in London, working on time series prediction for estimation of future prices of properties in London.

Helmi Fraser (2017 cohort) is interning for 3 months at MathWorks in Cambridge where he is a member of the Deep Learning team.

Jamie Roberts (2016 cohort) has an internship on the Connect-R grant which is developing autonomous robots for extreme environments.



Raluca Scona (2014 cohort) did an internship with NVIDIA Research in Seattle where she worked on robot manipulation.

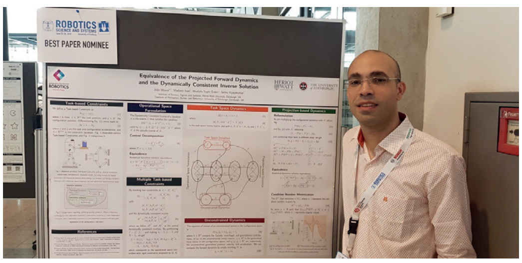
Mark Campbell (2016 cohort) worked at Dstl contributing to the Stone Soup open-source tracking project and the development of an autonomous telescope for Space Situational Awareness.

Academic awarded Royal Society Industry Fellowship

Stefano Albrecht has been awarded a Royal Society Industry Fellowship to work with UK-based company FiveAI, to research and develop artificial intelligence technologies for autonomous vehicles. The 4-year project started in January 2019 and will focus on enabling self-driving cars to make accurate predictions and safe decisions by drawing on research from artificial intelligence and machine learning. This involves a number of difficult questions, such as how predictions should incorporate the past behaviour of cars in various situations as well as contextual information such as road layout, traffic lights, and pedestrians. In many cases the self-driving car will be uncertain about its predictions, and a technical challenge is how the car may efficiently account for such uncertainty when making decisions.

Best Paper Award for CDT student

João Moura received a best paper award nomination at the Robotics: Science and Systems 2019 conference for his paper "Equivalence of the Projected Forward Dynamics and the Dynamically Consistent Inverse."
The conference committee accepted 85 papers out of 274 papers submitted (31% acceptance rate), of which 5 were nominated for best paper award.



Student Activities

CDT students host joint Robotics CDT conference

Students from the Centre successfully hosted the third annual student conference held jointly with the EPSRC Robotics CDTs in Bristol, Edinburgh and Oxford on the 3rd and 4th June. Fellow students from Bristol and Oxford arrived in Edinburgh on the Sunday evening and had the opportunity to take a bus tour of the city.

The first day of the conference started in earnest at 9am at the University of Edinburgh with coffee and welcome, followed by a keynote from Dr Ali Eslami of DeepMind. This was followed by presentations from students, poster sessions and tours of the Centre's world class lab facilities. Proceedings were then concluded by a second excellent keynote from Dr Margarita Chli, of ETH Zurich.

Networking continued into the evening with dinner at Vittoria on the Bridges with some hardy students summoning up energy to climb Arthur's Seat, Edinburgh's extinct volcano.

Heriot-Watt University hosted the second day of the conference with delegates able to choose from three workshop streams. These included a workshop to discuss the main issues encountered by women in robotics, led by the Women in Robotics Edinburgh team and female academics from the Centre; a session on effective public outreach and education; and tutorials on ROS, Graph Networks and Deep Learning.

The day also included a Dragons' Den style competition where students could pitch a business idea to a panel of 'Dragons'. The panel also gave presentations, with Dr Sandy McKinnon from Pentech Ventures advising participants 'How to think like a VC', and Paul Clark from Ocado, and Simon Watt from Karakuri talking about how robotics and AI are influencing their business processes.

Also on the panel was Dr Sandy Enoch, Founder and CEO of Robotical, an Edinburgh Centre for Robotics spin-out producing Marty, a robot who makes learning about Computer Science, Engineering and teamwork fun for children of all ages. Sandy spoke about his experiences as an entrepreneur.

All agreed that the conference was a great success and plans are already underway for the 2020 conference in Oxford.

Student Journal Club

The students of the RAS CDT run a Journal Club which meets every two weeks with two speakers presenting a recent paper in their field. It is now in its third year and the presentations continue to give rise to lively debates. Topics during the 2018/19 academic year have included "Online Gait Transitions and Disturbance Recovery for legged Robots" and "Deep learning for time series classification".

The Journal Club has no specific robotic theme, which encourages a broader spectrum of opportunities and challenges for the participants. Since the research work of the RAS CDT students is so diverse, the journal club provides a range of learning possibilities for the attendees, exposing the students to areas of research that they may not have otherwise encountered. Furthermore, it brings together the students from both universities and provides them with the chance to network with each other, either through discussion that arises from the questions presented to the speaker, or during the break over a few slices of pizza.

The journal club also allows the students to practice their presentation skills. The format of the presentation is entirely up to the speaker, which gives them the freedom to try out new presentation styles. What makes the Journal Club presentations challenging, however, is that students are presenting research in a field that may not be familiar to all the attendees. The speakers therefore need to learn how to make a presentation that is not only interesting and highlights the importance of the paper but is also accessible to all those attending.

Thanks to Calum Imrie who has organised the Journal Club on behalf of students for last three years.

Public Outreach

Centre hosts launch of New Girlguiding Scotland Digital Activity Badge

Edinburgh Centre for Robotics was delighted to provide the venue for the launch of Girlguiding Scotland's first digital activity badge designed to encourage girls of all ages to develop the skills they need for their digital future.

The Digital Scotland Challenge Badge was created in partnership with Skills Development Scotland (SDS) and Education Scotland, and aims to empower every girl to make the most of the opportunities technology offers.

Research by Girlguiding has highlighted that science and technology still continue to be perceived as more male subjects, with one in two girls saying science, technology, engineering and maths subjects were 'more for boys' while only 37% of girls said they would consider a job in tech. The Digital Scotland Challenge badge aims to change those perceptions and will teach young girls about computers, algorithms, creativity, design, and computational thinking, as well as highlighting career options in the industry. Fun activities and challenges have been created for Rainbows, Brownies, Guides and Rangers so girls of all ages can get to grips with technology – from mixing beats to animating adventures, and designing wearable tech to creating a robot maze.

Denise Spence, Chief Executive of Girlguiding Scotland, said:

"Giving girls a space to take on new challenges and learn new skills is a big part of what Girlguiding Scotland is all about. We're really excited to partner with Skills Development Scotland and Education Scotland on this new challenge badge. We know there is a world of opportunities for girls to discover in science and tech, but women continue to be under-represented in these fields. We hope initiatives like this will inspire and equip a whole generation of girls to make the most of their digital future. I'm looking forward to seeing girls across the country taking on the digital challenge badge and seeing everything they achieve."

Claire Gillespie, sector manager for digital technologies at SDS, said:
"This was such a great project to work on, and shows exactly what can be achieved when the third sector and the public sector work together for the common good. I have no doubt the badge holders will go on to great things in Scotland's tech sector in the future."

Alan Armstrong, Strategic Director with Education Scotland, added:
"We are delighted to have been part of this exciting project to create the challenge badge along with Girlguiding Scotland and Skills Development Scotland. Working towards the badge will encourage girls to get more involved in developing their digital skills as an important aspect of their learning across STEM subjects. This digital badge opens up a wealth of engaging opportunities for girls to build their confidence and their skills for work from the earliest age in Rainbows at 5 right up to Rangers at 18."

The tech theme of the new badge was reinforced at the launch with the help of robots from the Edinburgh Centre for Robotics at Heriot Watt University (HWU).

Professor David Lane, Founding Director of the Centre, said:
"We're delighted to be helping the Girl Guides, Skills Development Scotland and Education Scotland launch this new digital badge. Here at Heriot-Watt University we have a long history of encouraging girls to get involved in Artificial Intelligence and STEM subjects which are all part of the digital skills revolution."

Public Outreach (cont)

University of Edinburgh School of Informatics hosts School visits
In October the School of Informatics at the University of Edinburgh marked Ada Lovelace Day by inviting teenage girls to be computer scientists for the day.
Ada Lovelace is celebrated as the first female computer scientist who, despite having no access to formal school or university education, studied science and mathematics from a young age. Her birthday on the 9th of October is dedicated to women in STEM subjects and to creating new role models for girls and women in these fields.
Female pupils from two North Lanarkshire high schools, Coatbridge High and Coltness High, visited the University to get a taste of what it is like to be a computer scientist. On arrival they were introduced to Valkyrie and ANYmal, two robots from the Edinburgh Centre for Robotics Robotarium located in the Bayes Centre. They met with Professor Jane Hillston, current Head of School of Informatics, who told them about the breadth of research in the School and the opportunities for young scientists and Adela Rotar, a student in Artificial Intelligence and Computer Science, described her life as a student in the School of Informatics. The pupils then took part in two hands-on workshops; the first on online security, and the second on robotics which was delivered by students from the University's robotics society EaRS. Despite a busy day, the pupils enjoyed their experience of being a computer scientist.

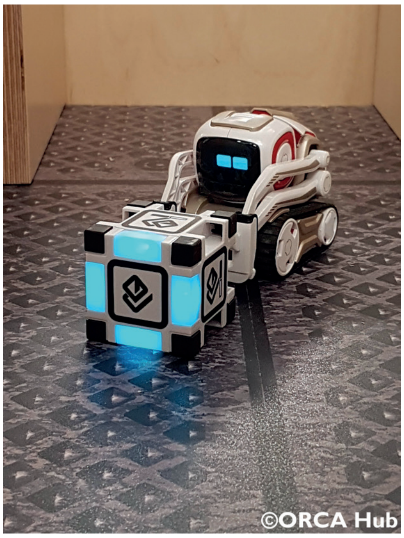
Earlier in the month the School hosted two visit from St George's School for Girls, who came to listen to Professor Sethu Vijayakumar's talk about the robots of the future. The girls were also given a tour of the Robotarium and talked to robotics students and staff about the robots they are working with.

CDT students support ORCA Hub at The Royal Society Summer Science Exhibition

CDT students and staff participated in the ORCA Hub's "Robots in the Danger Zone" exhibit at this year's Royal Society Summer Science Exhibition in London from 1st to 7th July 2019. The event aimed to showcase some of the most cutting-edge science and technology currently being undertaken in the UK through hands-on exhibits.

"Robots in the Danger Zone" was designed and led by CDT academic supervisor, Dr. Katrin Lohan (Heriot-Watt University), and ORCA RA, Dr. Alistair McConnell (University of Edinburgh). The exhibit aimed to show the goals of the ORCA Hub in miniature; specifically how robots can be used in hazardous offshore environments for guidance, navigation and control.

The exhibit was made up of three interactive zones featuring an offshore rig, an offshore wind turbine and a maze. Visitors to the stand had the opportunity to drive Cozmo robots around the zones to complete different tasks.



Hands-on exhibits

Welcoming Lord Willets and his wife, the artist Sarah Butterfield, to the ORCA Stand

Collaboration

ORCA Hub Trials

The second ORCA Capability Demonstrations, focussing on terrestrial and aerial activities, took place at the Fire Service College in Moreton-on-Marsh in late October. Over 50 research staff from across each of ORCA's partner institutions participated in the trials with strong attendance from industry representatives.

Human-robot interaction lead Professor Helen Hastie from Heriot-Watt University demonstrated MIRIAM (Multimodal Intelligent inteRactIon for Autonomous systeMs). MIRIAM is a conversational assistant used to increase situation awareness and help the operator understand what the robotics systems are doing and why.

At the rig site, the University of Oxford team demonstrated their quadruped robot, ANYmal, walking around the base of the rig via a planned route and autonomously planning footsteps to climb over a small wall. ANYmal then demonstrated autonomous gait switching before overcoming a dangerous surface to climb a small staircase and navigate inside the rig in the dark.

The University of Edinburgh team led by Dr Michael Mistry gave their ANYmal demonstration showing semi-autonomous sensing and intervention with mobile robots by manoeuvring ANYmal around both seen and unseen obstacles on top of the rig where it also had to contend with different challenging surfaces.

Dr Adam Stokes and his group from the University of Edinburgh discussed the further developments of The Limpet Robot. Multiple limpets were placed around the test area. Future demonstrations will include communication from the sensors back to a central station and show their monitoring capabilities either through showing real-time data or adaptable edge processing.

Dr Chang Liu and Dr Pouyan Khalili from Imperial College London gave demonstrations of autonomous sensor deployment using a large drone to carry the sensor from ground level to land on a specified point on top of the rig.

Using manned aviation practice as inspiration, The University of Liverpool team are working towards demonstrating the use of distributed simulation that can be used to generate evidence to help certify both offshore assets and the assets that gather the data themselves. Led by Dr Mike Jump, the Liverpool team demonstrated the progress that has so far been made including an initial distributed simulation example.

SICSA Workshop on Conversational AI

The Interaction Lab at Heriot-Watt University hosted the first SICSA Workshop on Conversational AI at Heriot-Watt University on the 12th of December, 2018.

The workshop brought together researchers and practitioners from both academia and industry for a series of presentations and discussions to explore some of the pressing issues around Conversational AI, including but not limited to: domain-generality, data-efficiency, incremental processing, multi-modality, grounding, disfluencies, real-time adaptation, semantic modelling and plasticity, and deep learning techniques.

Keynote speakers were Dr Mehrnoosh Sadrzadeh, from Queen Mary University of London who discussed "Exploring Semantic Incrementality with Dynamic Syntax and Vector Space Semantics".

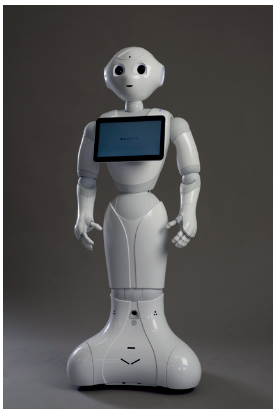
Dr Joel Fischer, from the University of Nottingham pointed out "The trouble with Alexa: voice interfaces and conversation design" and Professor Oliver Lemon from Heriot-Watt University talked about "Designing engaging open-domain conversational AI for the Amazon Alexa Prize".

Universities of Scotland event at the Scottish Parliament

Centre academic Professor Helen Hastie and CDT student Paola Ardón Ramírez attended a Universities of Scotland event at the Scottish Parliament on Tuesday 30th October.
The aim of this event was to address how institutions are equipping graduates with the skills needed for future jobs which is challenging as many of these jobs do not yet exist. It was clear from discussions that employers are increasingly prioritising skill-sets over subject focus, thus the broad range of transferrable skills developed through university education are in high demand. The event was hosted by Jenny Gilruth MSP, SNP member for Mid Fife and Glenrothes; with Richard Lochhead MSP, Minister for Further Education, Higher Education and Science, and Professor Andrea Nolan, Universities Scotland Convener as speakers.
Professor Hastie and Paola Ardón Ramírez shared the research that is being done in the Centre. They reported that many of the people they talked with knew the good reputation of the RAS CDT programme and were happy to share their ideas about new projects and how robotics and artificial intelligence might help develop those.

Workshop on Socially Assistive Robots and Technology for Healthy Ageing

Professor Lynne Baillie organised a workshop on Robotics for Healthy Ageing on Friday 12th October at Heriot-Watt University. The objective of the workshop was to share research work in this area and to consider how current projects could be developed to enable older people to maintain or even increase their daily living activities. The workshop also included a short talk on the Industrial Strategy Challenge Fund and other funding opportunities that could be accessed to fund further research. A tour of the Robotarium West rounded off the day with demos of the robots that are currently being used in the Centre for research into socially assistive robots.
The workshop generated a lot of interest with delegates attending from NHS Lothian, NHS Greater Glasgow and Clyde, Alzheimer's Society, Chest Heart Stroke Scotland, Scottish Government, Edinburgh City Council, Innovation Centres, Innovate UK, and Scottish Universities.



Collaboration (cont)

Heriot-Watt University China Alumni Reception and Industry Round Table
Heriot-Watt University graduates attended an exclusive event hosted by Vice-Chancellor, Professor Richard Williams in Beijing on Saturday 8th December. Graduates heard from Professor David Lane on the topic 'Transformational Innovation from Robotics and AI Engineering'. The keynote was followed by a panel discussion on what the future holds for robotics and artificial intelligence and the role they will play in our lives.

The University, with support from Scottish Development International, China Britain Business Council and the UK Dept for International Trade, also held an industrial round table event which featured Tencent, JD, Trio, Deep Blue, Intel Labs China, China Shipbuilding Industry Corporation, China Electronics Technology Group Corporation, JIangsu Industrial Technology Research Institute and Peking Union Medical College Hospital. All of these organisations travelled from Shanghai and elsewhere specifically to interact with Heriot-Watt University.

Centre Director to co-lead government initiative to scale up robotics sector

Professor David Lane, Director of the Edinburgh Centre of Robotics, has been named co-chair of the Robotics Growth Partnership alongside Paul Clarke, Chief Technology Officer at the online shopping and robotics giant, Ocado.

The ministerial appointments were announced by the Minister of State at the Department for Business, Energy and Industrial Strategy, Chris Skidmore MP, during a series of speeches emphasising the Government's commitment to realising investment of 2.4% of GDP in research and development by 2027.

The Partnership will bring together representatives from across industry, academia and government to develop and lead execution of a strategy and action plan that will accelerate growth of the UK RAS sector to match that of international competitors.

Professor Lane said: '**It has been an exciting five-years since the launch of the UK's RAS2020 strategy. Over £350m of UK Govt support matched by £150m of industrial gearing has supported development of Challenges, Assets, Skills and Clusters across the UK. Major centres of excellence have been established in Edinburgh, Bristol, London, Oxford, Manchester and Sheffield. Venture capital investment in RAS businesses has seen a tenfold increase to £250m in the last two-years. Other internal investments of over £1b have been made by British companies in consumer, grocery and transport sectors"**

He continued "**The task before us is to build on this national start-up of our nascent RAS industry, and scale-up to internationally competitive levels. Skills, investment, signposting, challenges, R&D, standards, certification, regulation, and ethics are just some of the focus areas where we must engage and bring a strategic focus. We want to make the UK one of the best places in the world to start and scale RAS businesses working internationally."**

Centre Visit to Indian Institute of Technology Kanpur

CDT students João Moura and Theodoros Stouraitis, and CDT Director Sethu Vijayakumar visited the Indian Institute of Technology in Kanpur to further ongoing collaboration between the Edinburgh Centre for Robotics and IIT Kanpur.

At an event hosted by Professor Laxmidhar Behera, the CDT delivered three talks on the following topics:

- Learning and Controlling Constrained Motions for Manipulation with Contacts;
- Partner Adaptive Collaborative Manipulation through Informed Hybrid Bilevel Optimization;
- Shared Autonomy for Robots in Dynamic Environments: Advances in Learning Control and Representations.

This visit, co-funded by the UK-India Education and Research Initiative (UKIERI), provided CDT students with the opportunity to engage with a large audience of young IIT robotics and AI students. They also had the chance to discuss recent and future progress of the joint project Smart Robots for Intelligent Warehousing: from Research to Translation with Professor Behera's research team.

Collaboration (cont)

Centre collaborates in ground breaking study to test new therapies for Parkinson's disease

A ground-breaking study is to test new therapies for Parkinson's disease on robots, replacing the need for animal testing. Over the next year, academics from Heriot-Watt University and the International Institute of Neuroscience in Brazil will join forces on the pioneering study: Neurorobotics Model of Parkinson's disease. Currently, scientists use rats in experiments to find new treatments but in this study, data already recorded from other animals in Brazil and robots in UK will be used instead.

Parkinson's disease currently affects more than 3 per cent of people over the age of 65, with figures set to double in the next 15 years. Despite numerous attempts there is still no cure and therapies often rely heavily on incomplete animal models of the disease. The brain regions linked to Parkinson's are also complex, limiting a complete understanding of the illness. Now, this study will combine neuroscience expertise with robotics, computational brain modelling and machine learning.

Dr Patricia A. Vargas, founding director of the Robotics Laboratory at Heriot-Watt University and lead collaborator said: **"This is a fantastic research project for our team to be working on. Not only will we possibly see new therapies for a debilitating illness, but it will also reduce the need to use animals for research.**

"Parkinson's disease affects individuals and families across the world, and scientists in Brazil and worldwide have been working hard to come up with new therapies but this project clearly demonstrates the positive affect robots can have on medical research, which can advance our knowledge about Parkinson's beyond what is obtained through the use of anatomical and physiological studies alone. This piece of research will be beneficial to millions of people across the world. We will help develop new knowledge and new therapies whilst reducing the need to use animals in this research altogether."

Annie Macleod, Scotland Director at Parkinson's UK said: **"As a charity, Parkinson's UK subscribes to the "3 Rs" policy—to reduce, refine and replace the use of animals in research wherever possible. We warmly welcome this study and the potential it holds for reducing or replacing the use of animals in future."**

The study will see robots expertise transferred from the Robotics Lab at Heriot-Watt University to the Edmond and Lily Safra International institute of Neuroscience in Brazil. The project was made possible by funding from The Newton Fund and Royal Society in UK under the Newton Advanced Fellowship scheme.

Dr Renan Moioli, the Overseas Fellow, said: **"The project will bring together scientists from UK and Brazil in an effort to further understand Parkinson's disease. The opportunity to work closely with one of the UK's top robotics group will strengthen our cooperation and advance our research groups."**

New Research Programmes

Neuro4PD Project : Neurorobotics Model of Parkinson's Disease, Grant number: NAF\R2\180773 – Royal Society/Newton Fund

Fellow (International Institute of Neuroscience, Brazil): Dr Renan Moioli
PI: Dr Patricia A Vargas; CO-Is : Prof David Corne, Dr Frank Broz and Dr Michael Lones, Heriot-Watt University

The Neurorobotics Model of Parkinson's Disease is an interdisciplinary project to gain further insights into the mechanisms of Parkinson's disease. This project will allow the transfer of the expertise of brain modelling, data mining and humanoid robotics from the Robotics Lab at Heriot-Watt University to the Edmond and Lily Safra International Institute of Neuroscience in Brazil. This project will support the development of techniques that can inform new Parkinson's disease therapies as well as contribute to reduce the number of animals used in research.
http://www.macs.hw.ac.uk/neuro4pd/

Human-Robot Interaction in Construction

Robotics is seeing renewed and rapidly growing interest in the Architectural, Engineering and Construction (AEC) industry for its benefits to tackle persistently low productivity and ever-present health and safety risks. While one may envisage future construction sites to be populated only with robots and entirely free of people, in the more foreseeable future robots are more likely to work alongside, in support of and in collaboration with human workers. This however raises challenges in developing safe and effective human-robot interaction (HRI).

Leveraging parallel development in Building Information Modelling (BIM) and AI, the project, led by Dr Frédéric Bosché (CyberBuild Lab), will develop a Mixed Reality (MR) -based Human-Robot Interaction (HRI) interface enabling humans to work/operate safely and effectively with robots and cobots in construction sites. The proposed solution will be validated using simulated and real-life case studies.

SPRING - Socially Pertinent Robots in Gerontological Healthcare

The ambition of the SPRING project is to develop a novel concept of social robots that is founded on modern statistical and deep learning science. The robot should be able to infer from input data how to (i) autonomously explore populated spaces, (ii) understand human behaviour, (iii) engage in multimodal dialogue with one or several users, and (iv) provide assistance to persons with special needs.

SPRING proposes to investigate novel methodologies with the general objective that social robotics technology should be flexible enough to adapt to the needs of society and not the other way around.

This H2020 project will run for four years with a budget of ~€8M, bringing together researchers from INRIA in France, the University of Trento in Italy, the Czech Technical University, Heriot-Watt University (Professor Oliver Lemon and Dr Christian Dondrup), Bar Ilan University in Israel, French company ERM Automatismes, PAL Robotics from Spain and the Broca Hospital in France.

ROBOTARIUM

ROBOTARIUM
EDINBURGH CENTRE FOR ROBOTICS

The Centre's state of the art ROBOTARIUM comprises four integrated and interconnected components which create a capability, unique in the world, for exploring collaborative interaction between remote teams of human, robots and their environments at all levels. It is transformational in the range of robot scales and environments that can be experimentally configured, and in the way the study of physical interaction through robot embodiment can be linked to the study of human interaction/expression, robot collaboration and real in-field remote operations for mapping and intervention.

The four components are as follows:

Interaction Spaces for humans and robots to work together in physically separate indoor spaces.

Field Robotic Systems comprising humanoids and unmanned vehicles for operations inside or outside the spaces.

MOBOTARIUM, a human driven sensorised and connected mobile vehicle for data assimilation/situation awareness and interaction for an operator with robots and intelligent agents in the field.

Enabling Facilities, underpinning the above components and comprising rapid prototyping and micro-assembly equipment for fabrication and inexpensive duplication of novel (bioinspired) robot embodiments, their sensors and their on-board computing. Also, state of the art computing accelerators with programmable hardware to develop power efficient computation suitable for autonomous deployments.

This national UK facility is available to researchers for proof of concept activities. We also welcome enquiries from industry who may wish to access our facility for product/service development.

For further information on equipment and availability, and how to book the facilities, please visit **http://www.edinburgh-robotics.org/robotarium**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Centre Impact

In the 6 years since the Edinburgh Centre for Robotics commenced operations in 2013 over £120m of core investment has been secured from the Research Councils, Industry and the Universities. This has established the buildings, equipment, staff, postdocs and students of a research and innovation Centre of international standing, providing an enhanced platform for additional project work in EU, EPSRC and MoD funded projects for 20 active academics, 20 postdocs and over 100 PhD students.

Beyond the scientific impact through high quality international publications, it uniquely operates a spiral approach to innovation with its industrial partners in programmes such as ORCA Hub (https://orcahub.org/). Industrial partners develop use cases and requirements for novel technologies in their planned products and services. From these, capability demonstrations are identified for applied researchers to attempt through a series of short term sprints. As these develop, so the industrial requirements evolve also, to converge on a final set of demonstrations with commercial relevance. Where the market conditions are right, this can then release resources for product development through industrial or venture investment.

Using this approach, the Centre's technologies and skills have created and supported successful international businesses including SeeByte, Coda-Octopus, Hydrason and Ice Robotics, alongside licensing for example with Touch Bionics. Recently Centre staff have supported the creation and growth of start-ups Robotical (through the Royal Academy of Engineering Enterprise Fellowship scheme) and Consequential Robotics with the international designer Sebastian Conran and the University of Sheffield. Our latest business Adabotics has recently spun out from the Centre seeded by our innovation fund, and is already winning awards in the Far East.

Our businesses have developed autonomous drones now commercially carrying out inspection of critical infrastructure, especially offshore in deep water. New forms of dolphin-inspired acoustic sensing are externally inspecting inside pipelines and tubular structures. New designs of prosthetic hands have benefited from advanced control system design using machine learning. From our work, affordable fully programmable, customisable walking robots are revolutionising how robotics, AI and STEM subjects are taught in schools and universities. New generations of companion and assistive robots are changing the way we support an ageing and isolated population. Shared-autonomy developments are reducing costs and dependency on manpower in drilling as oil prices fluctuate, and for order fulfilment in distribution warehouses and manufacturing.

The success of this research translation methodology has been recognized and resourced by the new National ROBOTARIUM institute scheduled to open in 2021. It will bring purpose built 5,000sqm buildings with living labs as the pivot for translation from research to products, co-located with international companies, startups and an incubator/accelerator.
The Centre is closely linked with the Alan Turing Institute through Programme Directorship of the RAI programme within the UK national centre for Data Science and AI. We engage at the highest levels of Government in both the UK and Scotland, with a ministerial appointment as co-chair of the Robotic Growth Partnership and through participation in the UK AI Council. These engagements allow the Centre to continue to develop and support the evolution of the UK as an international innovative economic force and a place where businesses and people come to develop their skills and technology.

This publication is available online at:

www.edinburgh-robotics.org/reports

This publication can also be made available in alternative formats on request.

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